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ARMY ENGINEER WATERWAYS EXPERIMENT STATION VICKSBURG--ETC F/G 13/11
FIXED-CONE VALVES, NEW MELONES DAM, CALIFORNIA. HYDRAULIC MODEL--ETC(U)
APR 81 S T MAYNARD, J L GRACE
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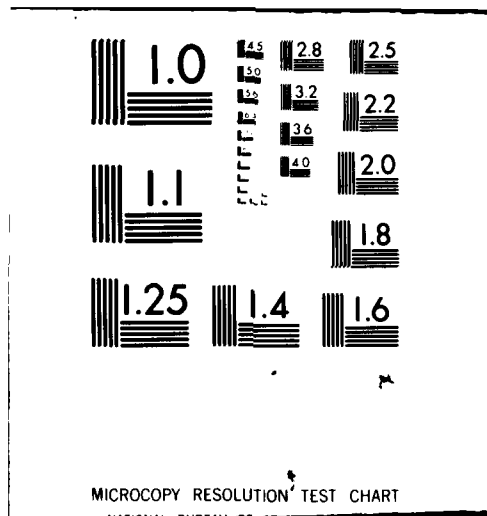
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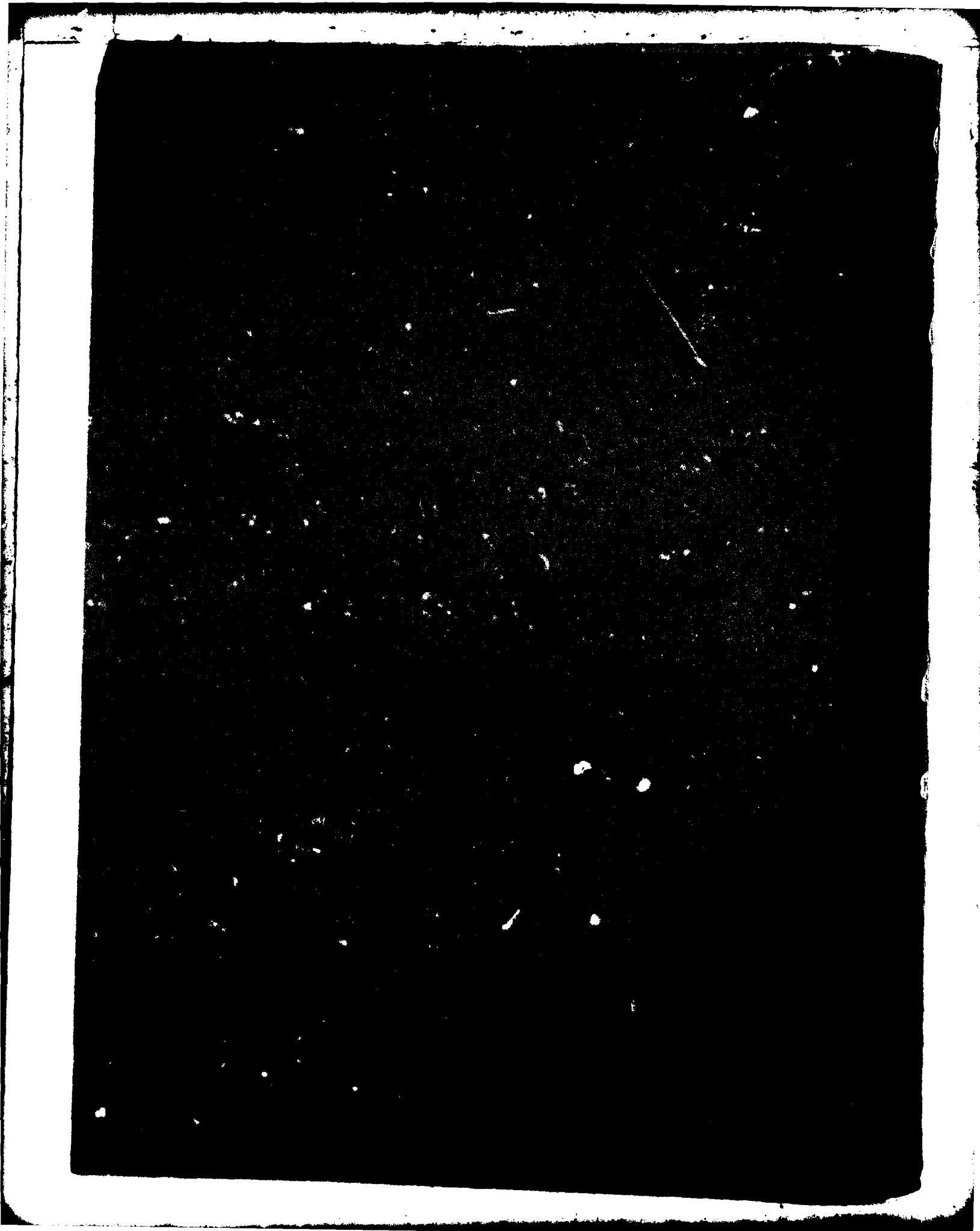
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20. ABSTRACT (Continued).

bends located just upstream of the valves. The upstream bifurcations in the flood control and irrigation outlet system caused substantial fluctuation of flow entering the 78-in.-diam valves. The discharge characteristics of the valves showed that the eight-vaned valves (without the center connecting hub design) used in the New Melones Dam outlet works have discharge coefficients slightly higher than conventional four- and six-vaned valves with center connecting hub. Approach conduit pressures were measured at all potential low pressure zones and no low pressures were measured. The original hood design was modified to reduce backslash on the valves. In the low-level outlet works, the backslash plate was moved downstream 4 ft from the original location and backslash was substantially reduced. In the flood control and irrigation outlet system a divergent cone was used in lieu of the plate to reduce backslash.

Results of the study are considered valid for use in designing against fatigue failure of the vanes. Although frequency spectra, developed from time-histories of pressure, strain, and dye injections, determined that predominant frequencies were low, the possibility of a resonant failure cannot be ruled out. Therefore, prototype tests have been initiated to address this possibility and to provide model-prototype correlation.

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PREFACE

The model investigation reported herein was authorized by the Office, Chief of Engineers, U. S. Army, on 19 January 1976, at the request of the U. S. Army Engineer District, Sacramento. The studies were conducted by personnel of the Hydraulics Laboratory and the former Weapons Effects Laboratory (WEL) (now a part of the Structures Laboratory, SL), U. S. Army Engineer Waterways Experiment Station (WES), during the period February 1976 to July 1978 under the general supervision of Messrs. H. B. Simmons, Chief of the Hydraulics Laboratory, and J. L. Grace, Jr., Chief of the Hydraulic Structures Division. The tests were conducted by Messrs. S. T. Maynard and H. R. Smith, under the supervision of Mr. N. R. Oswalt, Chief of the Spillways and Channels Branch. Technical assistance was obtained from Dr. Jesse Kirkland (former employee) and Mr. Bob Walker of SL (WEL). Instrumentation support was obtained from Messrs. Homer Greer and S. W. Guy. This report was prepared by Messrs. Maynard and Grace.

During the course of the model investigation, Messrs. J. H. Douma, R. H. Bruck, and Sam Powell of the Office, Chief of Engineers; Messrs. Ted Albrecht and A. E. Wanket of the South Pacific Division; and Messrs. G. C. Weddell, Harold Huff, Stan Dewsnap, Herman H. (Bud) Pahl III, L. A. Whitney, and John Tang of the Sacramento District visited WES to observe model testing and discuss test results.

Commanders and Directors of WES during this testing program and the preparation and publication of this report were COL G. H. Hilt, CE, COL John L. Cannon, CE, and COL Nelson P. Conover, CE. Technical Director was Mr. F. R. Brown.

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CONVERSION FACTORS, U. S. CUSTOMARY TO METRIC (SI)
UNITS OF MEASUREMENT

U. S. customary units of measurement used in this report can be converted to metric (SI) units as follows:

<u>Multiply</u>	<u>By</u>	<u>To Obtain</u>
cubic feet per second	0.02831685	cubic metres per second
feet	0.3048	metres
feet per second	0.3048	metres per second
feet per second per second	0.3048	metres per second per second
inches	25.4	millimetres
kips (force) per square inch	6.894757	megapascals
miles (U. S. statute)	1.609344	kilometres
pounds (force) per square inch	6894.757	pascals
square feet	0.09290304	square metres
tons (2000 lb, mass)	907.185	kilograms

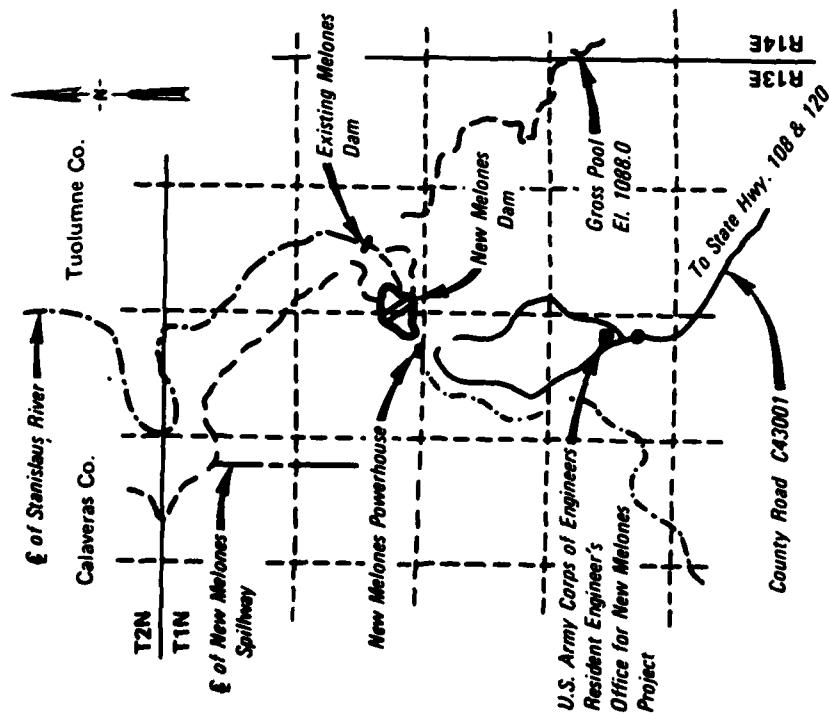
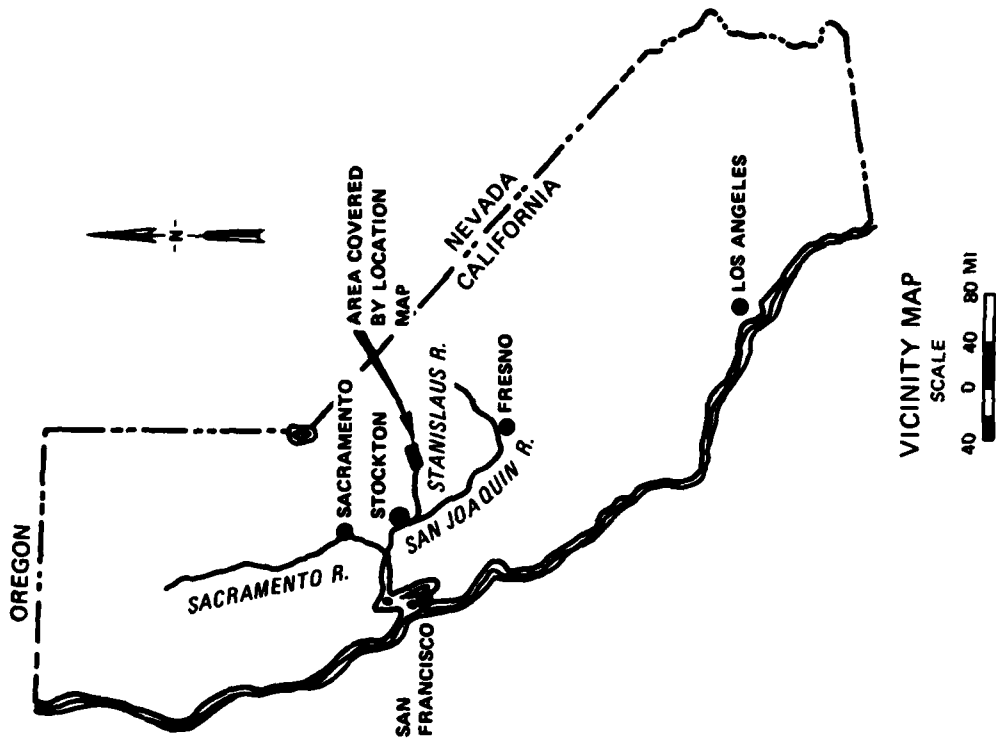


Figure 1. Vicinity and location maps

FIXED-CONE VALVES, NEW MELONES DAM, CALIFORNIA

Hydraulic Model Investigation

PART I: INTRODUCTION

Pertinent Features of the Prototype

1. New Melones Dam is located on the Stanislaus River near Sacramento, California. The vicinity and location maps and details of the project are shown in Figure 1 and Plate 1, respectively. The adopted plan includes a rock-fill dam; a multiple-purpose tunnel with outlet facilities for hydropower, flood control, and irrigation releases; a powerhouse; an ungated detached spillway; and the low-flow and flood control and irrigation outlet works.

2. The dam, a rolled rock-fill section with a central impervious core inclined upstream of the axis, is located about 3/4 of a mile* downstream from the existing Melones Dam. The embankment has a maximum height above streambed of about 625 ft and a crest length of about 1,560 ft. The rock-fill dam is arched upstream on a 2,000-ft radius. Crest elevation of the embankment is 1135.0,** providing 11.0 ft of freeboard above spillway design flood pool. The crest width is 40 ft and the upstream and downstream slopes, down to el 1113.3, are 1V on 2H and 1V on 1.9H, respectively.

3. A multipurpose outlet works for diversion, flood control, irrigation, hydropower, and other purposes is located in the right abutment of the dam. The outlet works consist of a 23-ft-diam multipurpose tunnel which had a low-level intake for diversion during construction; a multipurpose high-level intake for flood control, hydropower, and irrigation; a 55-ft-diam surge tank for pressure relief due to water

* A table of factors for converting U. S. customary units of measurement to metric (SI) units is presented on page 3.

** All elevations (el) cited herein are in feet referred to mean sea level (msl).

hammer action; two 17-ft-diam power tunnels and steel penstocks branched into two 174-in.-diam butterfly valves and two 14.5-ft-diam steel penstocks to serve turbines in the powerhouse; a 13-ft-diam tunnel and steel penstock equipped with a bifurcation at its downstream end to accommodate two 96-in.-diam ring follower gates, two 78-in.-diam fixed-cone valves and two 18-ft-diam hoods for control of flood and irrigation releases; two separate 6-ft-diam low-level outlet works, independent of the 23-ft-diam multipurpose tunnel, equipped with two 72-in.-diam ring follower gates, two 66-in.-diam fixed-cone valves and two 15.5-ft-diam hoods for control of diversion releases; and a tailrace channel. Tunnel plugs were installed in the diversion inlet and outlet tunnels after completion of diversion and before the outlet works operated as a pressure tunnel. The fixed-cone valves at New Melones Dam are eight-vaned valve designs having 1.75-in.-thick and 2.25-in.-thick vanes in the low-level outlet works and the flood control and irrigation outlet system (FC&I), respectively.

4. The powerhouse is located about 700 ft downstream from the toe of the rock-fill dam on the right bank of the Stanislaus River, opposite the existing Melones powerhouse. Two 14.5-ft-diam penstocks from the multipurpose tunnel serve the two turbines. Maximum gross head, at pool el 1088.0, is about 585 ft; minimum gross head, at pool el 808.0, will be about 303 ft; and design head, at pool el 971.0, will be about 466 ft when the reservoir fills. The powerhouse consists of two generating units and an erection bay, all complete with superstructure. Two 166,667 kva generators, at 0.9 power factor, can produce the required 300,000 kw. One 375-ton overhead traveling bridge crane is used to handle generator and turbine components and other powerhouse equipment during maintenance. A 230-kv switchyard is located about 2,000 ft downstream from the powerhouse. Overhead transmission lines are provided between the powerhouse and switchyard. A 90-ft-wide tailrace channel for the powerhouse was excavated in the streambed for a distance of approximately 2,150 ft.

5. An ungated detached spillway was excavated through the saddle approximately 2 miles northwest of the damsite to Bowman Gulch to carry

spillway flows to Bean Gulch, a tributary entering the Stanislaus River about 2,000 ft downstream of the powerhouse. This spillway channel is about 6,000 ft long with a maximum cut of approximately 250 ft on the center line. A broad-crested sill set at gross pool el 1088.0 and at a distance of about 2,190 ft downstream of the channel entrance provides a positive control for spillway flows. The control sill extends across the channel and up both banks to the top of the spillway design flood pool, el 1124.0. The channel has a bottom width of 200 ft and side slopes of 1.0V on 0.5H in rock and 1.0V on 1.5H in overburden, with 20-ft-wide berms at 40-ft intervals in elevation. The approach channel was excavated to invert el 1086.5 and the return channel downstream of the crest was excavated to a slope of 0.03 ft/ft beginning at the crest.

Purpose of Model Studies

6. The primary purpose of the model study was to determine the pressures and associated frequencies acting on the vanes of the fixed-cone valves for design purposes. Several prototype fixed-cone valves have experienced failure due to vane destruction. Mercer* did an analysis of existing fixed-cone valve installations and developed a parameter to determine if a valve is designed properly. The New Melones valves were designed on the safe side of Mercer's parameter. Mercer's analysis was based on conventional fixed-cone valves in which the vanes are connected to a center hub, whereas the vanes of the New Melones fixed-cone valves are not connected to the center hub. The structural advantage of either valve has not been determined to date. Because of unusual approach flow conditions, and relatively high head-large valve diameter combination at New Melones Dam, the model study was needed to measure the pressures on the vanes so that a structural analysis could be performed. Consequently, the structural integrity of the valve could be addressed by the structural analysis. Secondary purposes of the model study were

* Albert G. Mercer, "Vane Failures of Hollow-Cone Valves," IAHR-AIRH Symposium 1970, Stockholm, Sweden.

to determine discharge characteristics, pressure conditions in the approach conduits, and hood performance for both the FC&I and the low-level outlet works. Also, the models were used to observe flow conditions in the combined bends of the low-level outlet works and both bifurcations in the FC&I.

PART II: THE MODELS

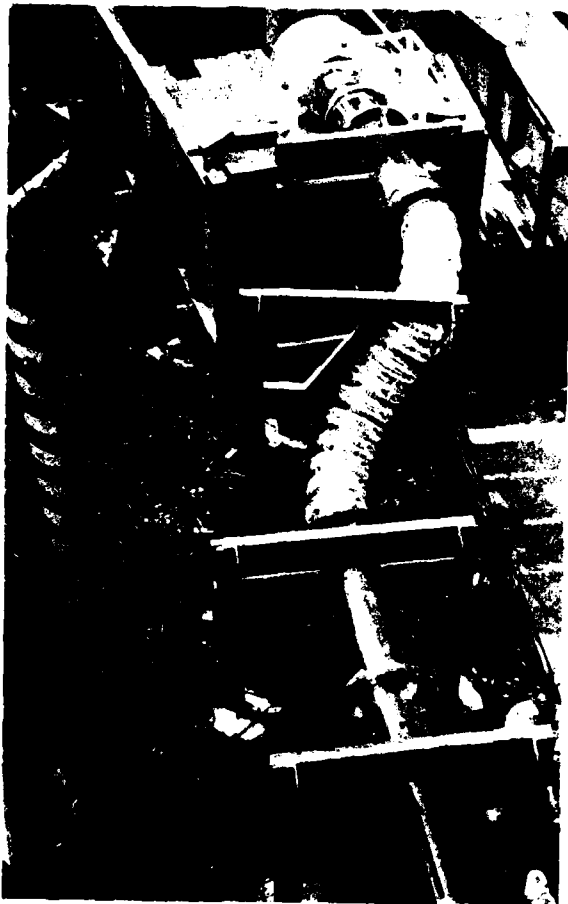
Description of Models

7. Two models were used in the investigation: a 1:12-scale model of the low-level outlet works and a 1:12-scale model of the FC&I.

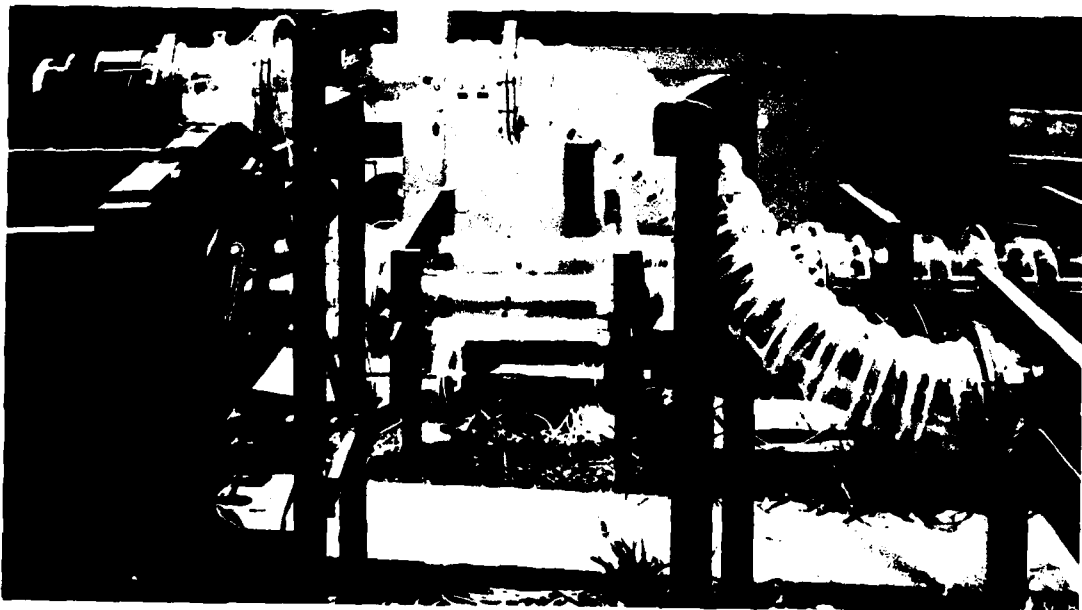
8. The 6-ft-diam low-level outlet works model (Figure 2a, Plate 2) reproduced 120 ft of the 6-ft-diam approach conduit, the combined bends (Figure 2b), the 66-in.-diam fixed-cone valve (Figure 3a), the valve pit, and the 15.5-ft-diam hood. The model reproduced only one of the two conduits (right side looking downstream) in the low-level outlet works since both sides operate independently. Molded plastic was used to reproduce the conduit, valve pit, and hood. The fixed-cone valve is shown discharging into the atmosphere in Figure 3b and flow exiting from the hood is shown in Figure 4.

9. The FC&I model (Plate 3), reproduced 100 ft of the 23-ft-diam diversion tunnel, the upstream bifurcation (Figure 5a), the diversion tunnel plug, the 13-ft-diam conduit, the downstream bifurcation (Figure 5b), the 8-ft-diam conduits, the 78-in.-diam fixed-cone valves, the valve pits, the 18-ft-diam hoods (Figure 6), and the splash pad.

10. The model valves were supplied by the contractor to the U. S. Army Engineer District, Sacramento (SPK), and instrumented outside of the U. S. Army Engineer Waterways Experiment Station (WES). Unlike conventional fixed-cone valves, the vanes of the valves at New Melones Dam are not connected by a center hub (Figure 7). Instead, each vane connects to the cone independent of the other vanes. The fixed-cone model valves were instrumented with transducers as shown in Plate 4 and strain gages were installed at the base of vane V. The pressure transducers used on the vanes, shell, and cone of the fixed-cone valves were 1/4-in.-diam, flush-mounted, with a range of 0 to 25 psi. One of the eight vanes, the master vane, was instrumented with four pairs of transducers, and the other seven vanes were instrumented with one pair of transducers. The strain gages were incorrectly installed in the low-level outlet works valve outside WES and therefore no strain data were

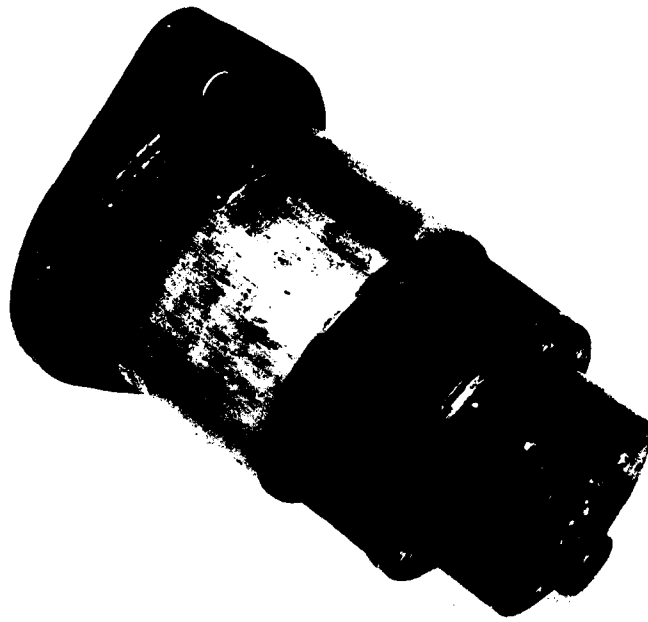


a. approach conduit

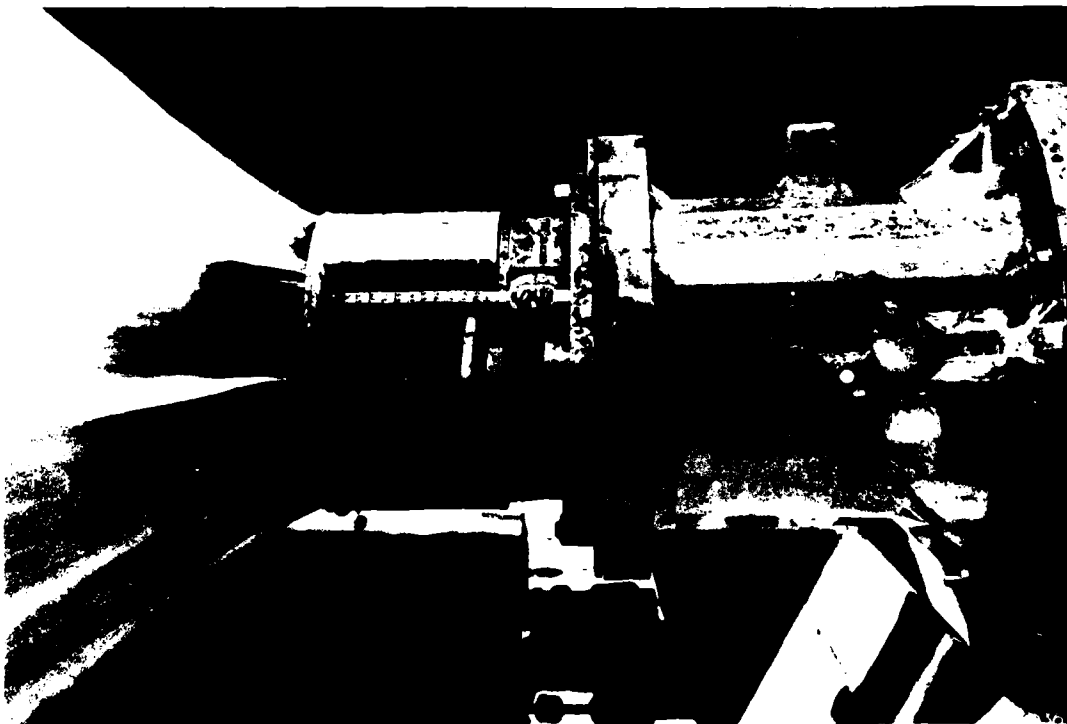


b. Combined bends

Figure 2. Low-level outlet works model



a. 66-in.-diam valve



b. Valve discharging into atmosphere

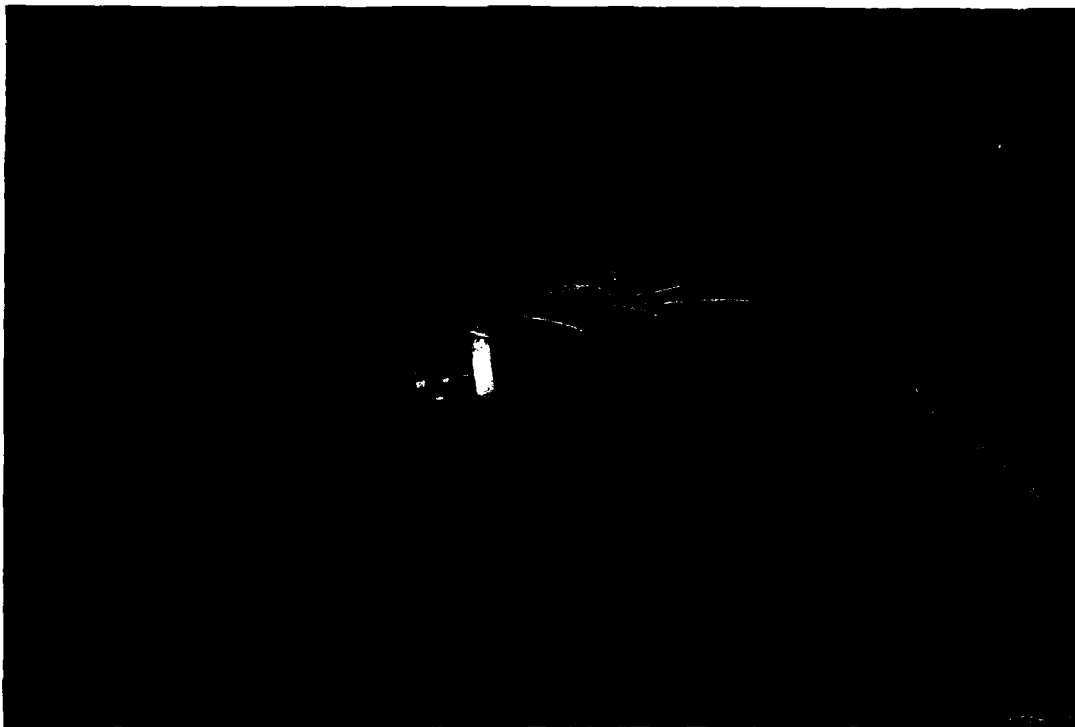
Figure 3. Low-level outlet works model, fixed-cone valve



Figure 4. Low-level outlet works model,
flow exiting 15.5-ft-diam hood

obtained. Only one of the 78-in.-diam fixed-cone valves was instrumented with both transducers and strain gages. The other 78-in.-diam valve was uninstrumented and was used only to control discharge. Early in the model study, consideration was given to the use of structurally similar model valves. This would have allowed reproduction of any interaction between the valve and the water flowing through the valve. The problems associated with constructing, instrumenting, and testing a structurally or quasi-elastically similar valve were considered formidable due to proprietary considerations. Therefore, the decision was made to use model valves fabricated by the manufacturer of the prototype valves which were similar hydraulically but very "stiff" structurally.

11. Water used in operation of the models was supplied by pumps and discharges were measured by a calibrated transition for the FC&I and a calibrated orifice plate for the low-level outlet works. Average pressures in the approach conduits were measured with piezometers and the instantaneous pressures in the approach conduit and model valve were



a. Upstream bifurcation



b. Downstream bifurcation

Figure 5. FC&I model bifurcation



Figure 6. FC&I model, valve pit and 18-ft-diam hoods



Figure 7. Model valve; 8-vaned configuration with no center connecting hub

measured with transducers. Dye was injected into the model to study flow patterns in the approach conduits. Visual observation was used to assess the performance of the hoods and backslash plates.

Scaling Relations

12. In determining the similarity criteria applicable to the New Melones fixed-cone valves model study, consideration was given to all forces within the system. Inertia is a dominant force that must be considered in the analysis. Gravity is the driving force behind the flow through the system but has no significant effect on the streamlines of flow within the valve and conduit because the force of gravity is balanced throughout the system. However, in the study of the valve hoods and hood jet trajectory, gravity must be considered a significant force. Other forces such as surface tension and compressibility do not affect the problems considered in the New Melones study. Fluid pressure is a significant force and must be considered in the analysis. Viscous or friction effects are significant in closed conduit systems. However, an exact representation of the prototype resistance cannot be achieved in the model because the conduit boundaries in the model and prototype are both hydraulically smooth. This results in different resistance coefficients in model and prototype because of the difference in Reynolds numbers. This difference in resistance coefficients was compensated for by reducing the length of the model conduit. However, the amount of reduction is applicable to one discharge only; for all other discharges, the friction losses will be different from the prototype. Fortunately, "experience has shown that the influence of errors caused by a minor discrepancy in frictional resistance will not materially affect the validity of the model results when R for the model exceeds 1,000,000."* This is true because inertial effects dominate the effects of surface resistance in the type of problem being studied for design of the New Melones fixed-cone valves and appurtenances.

* H. Rouse, ed. 1950. "Engineering Hydraulics," Proceedings, Fourth Hydraulic Conference, Iowa Institute of Hydraulic Research, 12-15 Jun 1949, Wiley, New York.

13. Therefore, the only forces of significance in the New Melones fixed-cone valves study are inertia, fluid pressure, and gravity. The Euler number as discussed by Rouse* is a dimensionless parameter relating inertial forces to fluid pressure forces.

$$E = \frac{V}{\sqrt{2 \Delta p / \rho}}$$

where

E = Euler number

V = velocity

Δp = differential pressure

ρ = fluid density

The Froude number is a dimensionless parameter relating inertial forces to gravity forces.

$$F = \frac{V}{\sqrt{gD}}$$

where

F = Froude number

V = velocity

g = gravity

D = characteristic length

For dynamic similarity (similarity of hydraulic forces in model and prototype) between a geometrically similar model and the New Melones prototype, the Euler and Froude numbers must be made the same in model and prototype. To ensure the same Euler number in model and prototype, the model must be built and operated at Reynolds numbers large enough that viscous forces are small compared with inertial forces as in the prototype. According to Rouse, the Reynolds number in the model should be greater than 10^6 .

* H. Rouse. 1956. Elementary Mechanics of Fluids, Wiley, New York.

14. The scaling relations applicable to Froudian modeling were used to ensure the same Froude number in model and prototype. The required length ratio was determined to be 1:12 for both the FC&I and the low-level outlet models so that the model Reynolds number would be about 10^6 . The resulting Reynolds number in the model was 0.8×10^6 for the low-level outlet and 1.9×10^6 for the FC&I at the maximum flow conditions. At these model Reynolds numbers the Euler numbers should be the same in the model and prototype, ensuring dynamic similarity. The appropriate scaling relations used are as follows:

<u>Dimension</u>	<u>Ratio</u>	<u>Scale Relations</u>
Length	L_R	1:12
Time	$T_R = L_R^{1/2}$	1:3.464
Velocity	$V_R = L_R^{1/2}$	1:3.464
Discharge	$Q_R = L_R^{3/2}$	1:498.8
Pressure	$P_R = L_R$	1:12

PART III: TEST RESULTS

15. Results for both the FC&I and the low-level models consisted of determination of discharge characteristics of the valves, design pressures on the fixed-cone valves, approach conduit flow conditions, and hood performance.

Discharge Characteristics

16. Details of the valve dimensions and how valve openings were measured are shown in Plate 5. The design specifications for the 66-in.-diam fixed-cone valves in the low-level outlet works required a discharge of 750 cfs at a net head of 29 ft and at full valve opening. A combined discharge of 9,000 cfs at a net head of 490 ft and at full valve opening was required for the 78-in.-diam valves in the FC&I. The discharge rating curves for the 66-in. and both 78-in. valves are shown in Plates 6 and 7, respectively. Both valves meet the discharge specifications. The discharge coefficient C in the equation,

$$Q = CA \sqrt{2gH}$$

where

Q = discharge, cfs

A = area of conduit immediately upstream of valve, ft^2

g = acceleration due to gravity, ft/sec^2

H = net head on valve, static + velocity head, ft

is shown as follows for various valve openings:

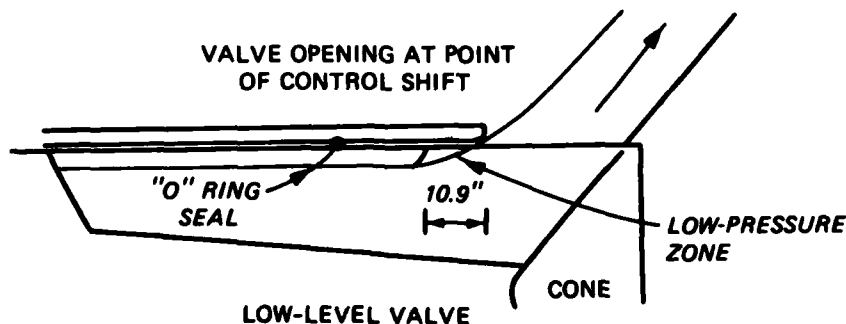
<u>Low-Level Valve</u>		<u>FC&I Valve</u>	
<u>Sleeve</u>	<u>Discharge</u>	<u>Sleeve</u>	<u>Discharge</u>
<u>Travel, in.</u>	<u>Coefficient</u>	<u>Travel, in.</u>	<u>Coefficient</u>
5.2	0.13	6.00	0.12
8.2	0.23	9.53	0.22
11.2	0.31	13.05	0.31
14.2	0.40	16.58	0.41

(Continued)

Low-Level Valve		FC&I Valve	
Sleeve Travel, in.	Discharge Coefficient	Sleeve Travel, in.	Discharge Coefficient
17.2	0.47	20.10	0.49
20.2	0.56	23.63	0.57
23.2	0.64	27.15	0.66
26.2	0.72	30.68	0.74
≥27.7	0.75	≥31.2	0.77

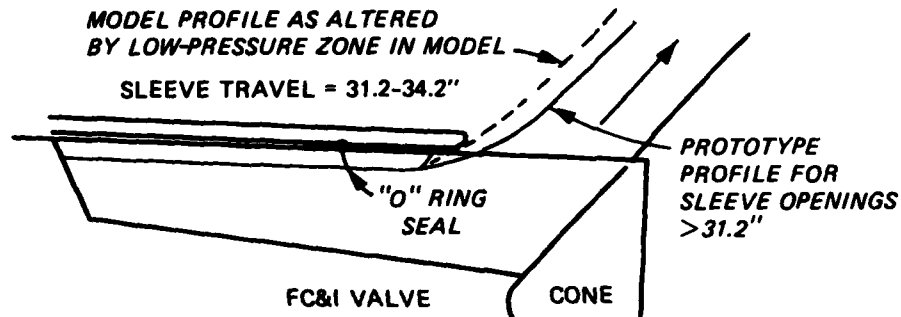
A comparison of these discharge coefficients with coefficients set forth in Hydraulic Design Criteria Chart 332-1/1* is shown in Plate 8.

17. The point at which control of flow shifts from the sleeve to the valve body was a concern during the design phase and became of serious concern when prototype FC&I valves experienced severe vibrations at sleeve openings observed to be the control shift opening in the prototype. Initial model test results showed that the control shift occurred at sleeve travels of 34.2 in. in the FC&I and 29.2 in. in the low level. Those values were determined by closing the model valves until control was definitely at the sleeve and then slowly opening the valves until the control shift occurred. At the control shift point the flow exiting the valve suddenly changed from a milky color to clear. However, scale effects or geometrically different dimensions in the manufacturer furnished model were causing the control shift to occur at a larger sleeve travel in the model than in the prototype when the model valve was being opened. This difference between the model and prototype was probably caused by the low-pressure zone shown in the diagram below.

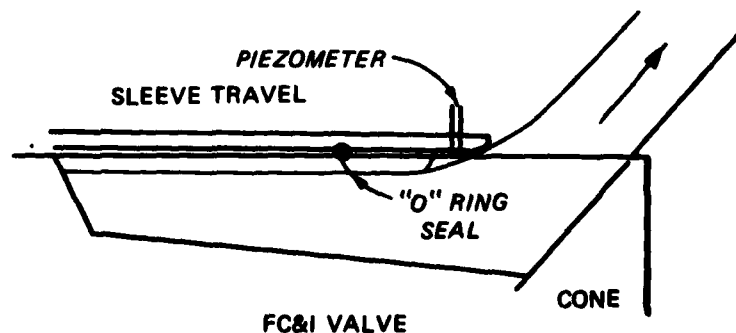


* U. S. Army, Corps of Engineers, "Hydraulic Design Criteria," prepared for Office, Chief of Engineers, by U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss., issued serially since 1952.

In the model, where velocities are relatively low, the pressure is not low enough to result in cavitation or vaporization of the water in this zone. Consequently the only significant effect of this low-pressure zone is to alter the point at which control shifts in the model when the valve is being opened. This effect is shown below.



The effect of this low-pressure zone in the prototype can be significantly different because exit velocities approach 110 fps at the heads observed during the prototype FC&I valve tests. At these velocities the pressure in this zone may be low enough to result in cavitation. At a valve opening equal to the point of control shift, this zone may be experiencing an alternating control shift and cavitation in the low-pressure zone which results in vibration and large pressure fluctuation observed during the prototype FC&I tests. This could explain why the vibrations did not occur in the low-level prototype tests. During these tests exit velocities were 50-60 fps which may not have been high enough to trigger cavitation in the low-pressure zone. Measurements were made in the model of the FC&I valve to evaluate the magnitude of low pressure in this zone. Pressures were measured at the location shown below.



The following pressures were measured in the FC&I valve at the same heads tested in the prototype tests.

Pool El	Sleeve Travel, in. in Percent (%) Open	Model Pressure, ft*	Prototype Pressure, ft*
804	30.7 (80)	0.5	6.0
804	31.4 (82)	-0.9	-10.8
804	31.7 (83)	-1.8	-21.6**
804	32.1 (84)	-2.8	**
804	32.4 (85)	-3.4	**
804	32.8 (86)	-3.7	**
804	33.1 (87)	-4.4	**

* Pressures are in feet of water.

** Certain cavitation in prototype.

These data show that significant low pressures exist at valve openings equal to and slightly greater than the control shift valve opening. These data also show that the low-pressure zone persists in the model at conditions that would likely result in cavitation in the prototype. The model valves correctly reproduced the control shift when the valves were being closed. This control shift was observed for a full range of heads in both the low-level outlet and the FC&I and no significant change as a function of head was observed. In the model, the control shift was observed at 31.2 in. (82%) and 30.68 in. (80%) in the FC&I and 27.7 in. (85%) in the low level. If valve openings are limited to some value less than given above, safe operation of the valves could be expected regarding discharge control-shift-induced vibration. This type of vibration can be structurally disastrous if permitted for any appreciable duration. Personnel conducting the prototype valve tests and operating the powerhouse considered that an earthquake had occurred when the phenomenon was experienced with a relatively empty or low pool and head condition.*

* T. Fagerburg and D. Hart. "New Melones Fixed-Cone Valve Prototype Tests" (in preparation), U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

Design Pressures for the Fixed-Cone Valves

18. The design loadings to be used in the structural analysis were determined by monitoring pressures acting on transducers mounted on the vanes of the model valves. The combined bends in the low-level outlet works and both upstream bifurcations in the FC&I introduced a fluctuation of the flow upstream of the fixed-cone valves. This lateral fluctuation of flow created large loadings on the vanes of the fixed-cone valves. This fluctuation can be seen in the movement of dye injected into the model just upstream of the valve (Figure 8).

19. Before selection of design loading condition for the FC&I, tests were conducted to determine if either side of the downstream bifurcation experienced more severe flow conditions. Tests were conducted in which the instrumented valve was mounted on each side of the downstream bifurcation and pressures on the vanes of the model valve were monitored for the same combination of valve opening and net head. The pressure records on each side of the FC&I were compared and there was no indication of either conduit experiencing a more severe loading condition. All remaining tests to determine the design loading were conducted with the instrumented valve on the right side of the bifurcation looking downstream.

20. The first requirement in selecting a design loading was to determine which combination of sleeve travel and net head on the valve resulted in the most critical loading condition. Pressure data were monitored for the tests shown in the table below:

Model	Sleeve Travel, in. in Percent (%)	Net Head Feet of Water	Master Vane Location, Looking DS
	Open		
Low-level	9.7 (25)	418	12:00
Low-level	14.2 (40)	311	12:00
Low-level	20.2 (60)	218	12:00
Low-level	27.7 (85)	147	12:00
FC&I	11.3 (25)	599	12:00
FC&I	16.6 (40)	591	12:00
FC&I	23.6 (60)	580	12:00
FC&I	32.4 (85)	561	12:00

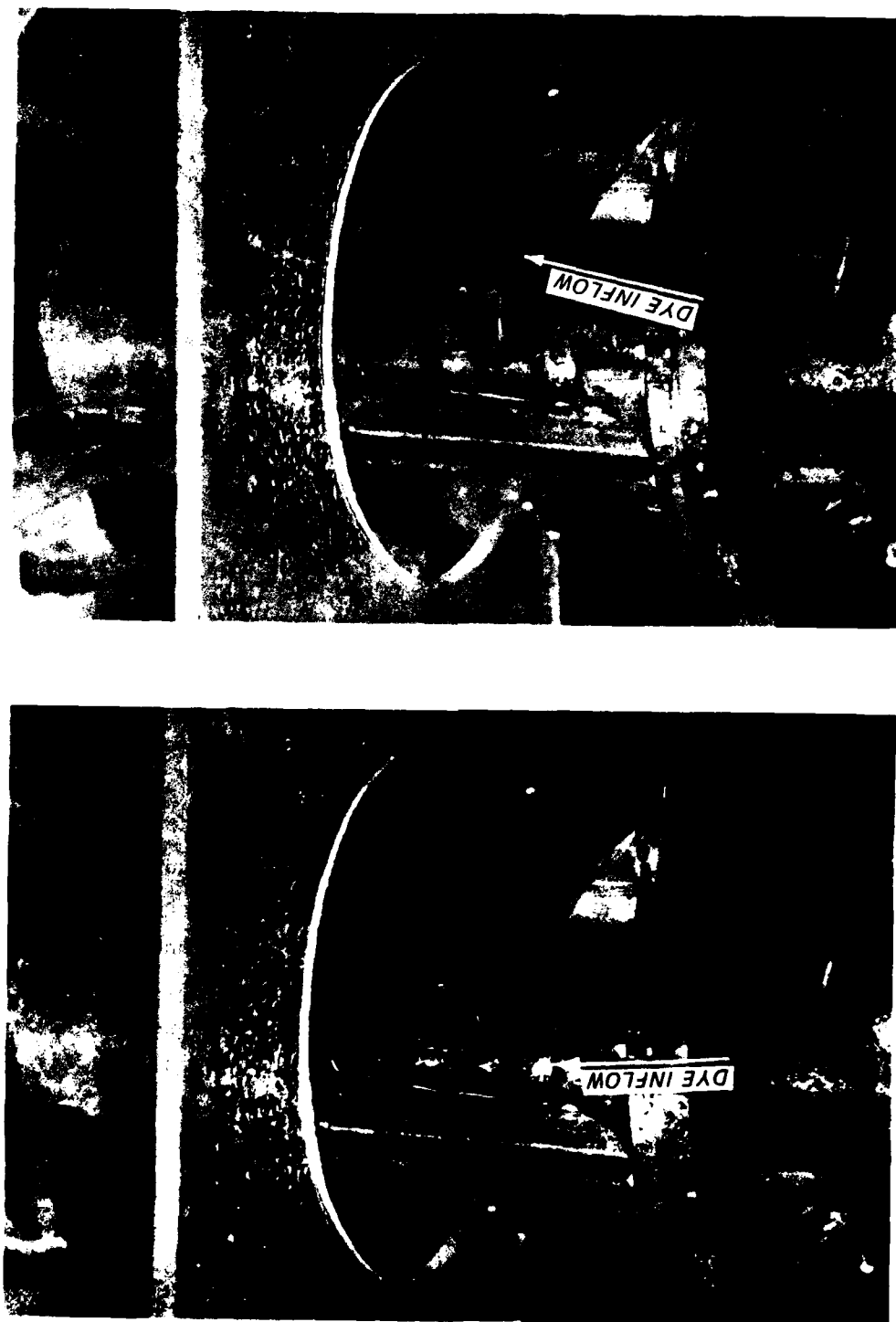


Figure 8. Low-level outlet works model, fluctuation of flow upstream of valve

For each test a time-history of the torque acting on the valve was determined by summing the differential pressure across all eight vanes at each instant of time. This differential pressure was obtained by taking the difference in pressure between transducers on opposite sides of the vanes. The time-history plots of the torque for all four conditions of the low-level outlet works are shown in Plates 9-12. Time-history plots of torque for the FC&I are shown in Plates 13-16. From these plots the most critical combination of valve opening and net head was determined to be 27.7 and 32.4 in. of sleeve travel at the maximum pool elevation for both the low-level and the FC&I, respectively. This was based on the magnitude of the average torque and the magnitude of the positive peak to negative peak variation of torque being largest at these combinations of valve opening and net head.

21. The next requirement in selecting a design loading required determination of the type of structural analysis to be used in designing the valve. At the outset of this study it was assumed that a dynamic analysis would be used to design the valve. A dynamic analysis requires a design loading at each instant of time. The dynamic analysis would be necessary to design the valve if the frequencies of the forcing function (the flowing water) were near the natural frequencies of the fixed-cone valve. The natural frequencies of the valve were determined by the contractor responsible for the design of the valve. The natural frequencies were determined for the 66-in.-diam valve and assumed to be the same for the 78-in.-diam valve. The frequencies of the forcing function were determined from the model by developing a spectrum of the amplitudes of the constituent frequencies from the time-history of torque acting on the valve. The frequencies for the critical valve opening and maximum pool are shown in Plates 17 and 18 for the low-level (1 Hz) and FC&I (0.5 Hz), respectively. The natural frequencies of the valve as determined by the contractor were well above the frequencies of the forcing function. The lowest natural frequency determined for the various modes of vibration was 40 to 50 Hz. Consequently, a static analysis was used in the design which required only the maximum loading condition and the predominant frequency associated with the loading. Considerable data analysis was

conducted to determine the maximum loading conditions for design of the fixed-cone valves. The time variations of all pressure data within the valve were analyzed in detail. Past experience at WES has shown the difficulties in using point pressures to determine total loads on hydraulic structures. The pressure transducers cover only a small portion of the total vane area, leaving a large vane area with unknown pressure distribution. Based on these considerations, SPK, SPD, WES, and OCE agreed to use the maximum differential pressure observed across any vane at any location in the valve as the maximum loading condition and as the pressure differential to be used over the entire area of the vane. Tests were run with the master vane at all eight locations and pressures were recorded at each transducer for each test. These tests were conducted for both the 66- and 78-in.-diam valves. The pressure data were digitized and time-histories were plotted for each transducer. Differential pressures were computed for each vane and recorded. The records were searched for the maximum pressure differential (always between I_D and I'_D) and the following table shows the maximum values at each master vane location.

Master Vane Location, Looking Downstream	Maximum Differential Pressure, Feet of Water	
	Low-Level Valve	FC&I Valve
12:00	77.5	92.8
1:30	79.1	107.0
3:00	71.0	90.5
4:30	61.7	90.5
6:00	55.8	129.4
7:30	41.4	117.4
9:00	60.0	64.0
10:30	103.2	123.1

A maximum differential pressure of 103.2 ft of water was observed at the D location with the master vane at 10:30 o'clock for the low-level outlet works valve. A maximum differential pressure of 129.4 ft of water was observed at the D location with the master vane at 6:00 o'clock for the FC&I valve. The time-history plots at I_D and I'_D and a digital listing for the low-level outlet works valve are shown in Plates 19 and 20, and Table 1, respectively. A digital listing of the time-history of pressure for the FC&I valve is shown in Table 2. The maximum

differential pressure determined from digitized data may not reflect the true maximum value because the length of record for the digitized data was limited to 10 sec (prototype time) due to computer storage limitations. Higher differentials might have been observed digitally if a longer period of record could have been analyzed. In fact, analyses of an analog signal representing 2 min in the prototype from transducers I_D and I'_D show a maximum differential pressure of 135.7 ft of water (58.8 psi) for the low-level outlet works fixed-cone valves. A portion of this analog signal showing the maximum differential pressure is shown in Plate 21. The 58.8-psi value was the most critical loading condition obtained in the model for the 66-in.-diam fixed-cone valve. Analysis of an analog signal for the FC&I valve shows that the value observed in the digital listing is the most critical loading condition for the 78-in.-diam fixed-cone valve.

22. The prototype frequency associated with this maximum loading condition (58.8 psi) was determined by developing an amplitude spectrum from the digital time-history data for transducers I_D and I'_D . Amplitude spectra are shown in Plates 22 and 23 for the 66-in.-diam and 78-in.-diam valves, respectively. Amplitude spectra for the differential pressure $I_D - I'_D$ are shown in Plates 24 and 25 for the 66-in.-diam and 78-in.-diam valves, respectively. The plots show a predominant frequency of less than 2.0 Hz for both the FC&I and the low-level valves, which is much less than the natural frequencies of the valves and their components.

23. An analysis was made to compare the frequencies determined from the oscillations seen in the flow when dye was injected in the low-level outlet works model to the natural frequencies of the valve. High-speed movies were taken of the dye injected upstream of the valve. The position of the dye relative to the conduit center line was recorded as a function of time and amplitude (position) spectra were developed from these data. Plate 26a is a plot of the amplitude spectrum associated with the small-scale turbulence and fluttering action of the injected dye that was observed periodically in the model. Plate 26b is a plot of the amplitude spectrum associated with the large-scale turbulence indicated by the clockwise to counterclockwise movement of the injected dye.

As in the case of transducers I_D and I'_D , the predominant frequencies are low relative to the natural frequencies of the valve.

24. An analysis was made to compare the frequencies determined from the time-history of deflection as measured on the pair of strain gages mounted on the opposite sides of vane V in the FC&I valve to the natural frequencies of the valve. The amplitude spectra are shown in Plate 27. Again, the predominant frequencies are low relative to the natural frequencies of the valve.

25. Testing of the FC&I model was conducted to determine the effects of one-valve operation on the vane loadings in the valve. The uninstrumented 78-in.-diam model valve was closed so that all of the flow would be passing through one leg of the downstream bifurcation. The instrumented valve was set at 32.4 in. of sleeve travel and a net head of 561 ft was established. Pressures on the vanes of the valve were recorded on tape, and the data were digitized and plotted. Plots of the time-history of pressure are shown in Plate 28a and 28b for locations I_D and I'_D , respectively. The frequencies associated with these time-histories are shown in Plates 29a and 29b for locations I_D and I'_D , respectively. A digital listing of the pressures is shown in Table 3. The maximum differential pressure at location D is equal to 90.5 ft of water. This value was exceeded by the differential pressure measured at location B that was equal to 96.8 ft of water. In either case, the design loading of 56.1 psi (129 ft of water) that was recommended for the 78-in.-diam fixed-cone valve was considered adequate in designing for one-valve operation. The Sacramento District Operations Manual states that the valves are to be operated in tandem.

26. Dye was injected in the FC&I valve model immediately upstream of the downstream bifurcation and the fixed-cone valve to determine if there is a discharge at which the flow becomes significantly less violent. The tests indicated that below a discharge of 4,000 cfs, the flow upstream of the valves in the FC&I outlet works is relatively straight with respect to the conduit center line. Above a discharge of 4,000 cfs, the flow is shifted away from the conduit center line indicating significant fluctuation of the flow and a greater angle of attack on the vanes

of the fixed-cone valves. The change in flow conditions occurred at 4,000 cfs for both one- and two-valve operation. Similar tests were conducted on the low-level outlet works and no change in flow condition was detected for reduced flows.

27. Summarizing, the design loading conditions to be used in the structural analysis of the fixed-cone valves are as follows:

	<u>Low-Level Valve</u>	<u>FC&I Valve</u>
Sleeve travel	27.7 in.	32.4 in.
H _{net}	147 ft	561 ft
Differential loading	58.8 psi	56.1 psi
Frequency	0.8 Hz	0.5 Hz

28. Additional model tests for both systems were conducted at a full range of heads lower than the heads used to design the fixed-cone valves. Results obtained from these tests will be compared with results obtained from prototype tests of the fixed-cone valves. If good correlation exists between model and prototype for the lower heads, then the model pressures obtained for maximum pool conditions and the method of valve design will be considered correct as far as fatigue failure is concerned. Results of the additional model tests are given in Appendix A.

Approach Conduit Flow Conditions

29. Average pressures in the approach conduit of the low-level outlet works were measured at the locations shown in Plate 30. Average pressures at each location for four combinations of sleeve travel and discharge are shown in Table 4. None of the piezometers indicate zones of low pressure. Average pressures in the approach conduit of the FC&I outlet works were measured at the locations shown in Plates 31-33. Average pressures at each location for eight combinations of sleeve travel and discharge are shown in Table 5. Again, none of the piezometers indicate zones of low pressure.

30. Tests were conducted to determine if the piping configuration at the upstream bifurcation of the FC&I outlet works was causing the

instabilities seen in flow leaving the bifurcation. Dye injected into the model at a point downstream of the 23- to 13-ft-diam bifurcation showed significant flow fluctuation. The potential for a "water whistle" effect exists between the upstream bifurcation and the tunnel plug in the 23-ft-diam tunnel. This zone may develop unstable eddies which would result in appreciable flow disturbance downstream. To address this possibility the tunnel plug was moved in the model to the location shown in Plate 34. Dye was injected after the plug was moved upstream and the flow fluctuation was still present. More tests were conducted to determine if the inlet conditions of the model were introducing unstable flow. Vertical rod baffles were installed in the 23-ft-diam model tunnel 100 ft upstream of the upstream bifurcation to stabilize any entrance flow instabilities, and again no change was seen in the movement of dye injected into the model.

31. Limited tests to monitor pressures in the upstream bifurcation of the FC&I outlet works were conducted to determine, if possible, the cause of the instabilities seen in the flow leaving the bifurcation. The flow conditions monitored were as follows:

<u>Test No.</u>	<u>Sleeve Travel, in.</u>	<u>Net Head on Valve, ft</u>
606	32.4	292
607	32.4	462

The locations where pressures were measured are shown in Plate 35 and the time-histories of pressures measured are shown in Plates 36 and 37 for tests 606 and 607, respectively. Amplitude spectra for tests 606 and 607 are shown in Plates 38 and 39, respectively. The pressure fluctuation at all three locations is about ± 20 ft of water for the 292-ft net head and ± 15 ft for the 462-ft net head. A comparison of the amplitude spectra (channels 3 and 7) shown in Plates 38 and 39 and the computed frequencies of vortex shedding from the cylindrical posts based in the Strouhal number is shown in the following tabulation for tests 606 and 607.

Test No.	Sleeve Travel, in.	Net Head ft	Post Diameter, in.	Predominant Frequency from Model Data, Hz	Computed Frequency Hz
606	32.4	292	16	2.3	4.3
606	32.4	292	9	2.3	7.6
607	32.4	462	16	3.5	5.4
607	32.4	462	9	3.5	9.6

Both the measured and computed frequencies show an increase with an increase in discharge. However, this analysis was not conclusive in establishing the cause of the flow instability of flow leaving the bifurcation.

32. Tests were conducted to determine the pressures and flow conditions at the splitter plate in the downstream bifurcation of the FC&I outlet works. First, the instantaneous pressures acting on the plate were measured with both 78-in.-diam fixed-cone valves open. The location at which pressure was monitored is shown in Plate 40. The following table shows the results of tests conducted to determine these pressures.

Sleeve Travel, in.	Net Head on Valve ft	Mean Pressure on Splitter Plate ft	Deviation About Mean Pressure ft
32.4	462	400	+20
32.4	292	252	+15

Next, tests were conducted to measure the average pressures acting on the splitter plate for one-valve operation. Low pressures may exist in the separation zone shown in Plate 40 when the right leg is closed and all flow is passed through the left leg. Average pressures measured on the splitter plate for one-valve operation with flow through the left leg are shown in the following tabulation.

Sleeve Travel, in.	Net Head on Valve ft	Mean Pressure on Splitter Plate ft
32.4	318	230
32.4	402	278
32.4	478	331
32.4	534	377

From these measurements, no low pressures are indicated.

Hood Performance

33. The original hood design (Plate 41a) for the low-level outlet works was tested at various combinations of percent opening and head on the valve and all tests exhibited excessive backslash (Figure 9). The ratio of the hood diameter to the valve diameter for both New Melones hoods is 2.8. This is close to the recommended ratio of 3.0 determined from previous WES tests.* The larger hoods result in less backslash and greater energy dissipation. The backslash plate height was increased from the original 1 ft 9 in. to 3 ft 3 in. The 3 ft-3 in. plate resulted in reduced amounts of backslash, but still more than is acceptable. Next, the 3 ft-3 in. backslash plate was moved downstream to a point where the plate was close to the jet and the resulting backslash was further reduced. The backslash plate was reduced to the original size and moved further downstream close to the jet, and the resulting backslash was low relative to the original design. This design is shown in Plate 41b and the resulting backslash at 27.7-in. sleeve travel at maximum pool and pool el 808.0 is shown in Figure 10a and 10b, respectively.

34. In an attempt to further reduce the backslash on the low-level valves, a segmented cone hood design was tested and developed in the model. Several cone angles and locations were tried before identifying the optimum design that resulted in the lowest backslash at all valve openings. This design is shown in Plate 41d and the resulting backslash with this design and an opening of 27.7-in. sleeve travel is shown in Figure 11.

35. The hood in the low-level outlet works was shortened in an attempt to keep the flow from converging after leaving the hood. This convergence of flow was likely due to the low-pressure zone within the jet and shortening the hood had little effect on the convergence.

* B. P. Fletcher. 1969 (15 Jan). "Howell-Bunger Valves, Summersville Dam," Memorandum Report, U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.



Figure 9. Low-level outlet works model, original hood design; maximum pool elevation



a. Maximum pool elevation



b. Pool el 808.0

Figure 10. Low-level outlet works model, revised back-splash plate location



Figure 11. Low-level outlet works model, segmented cone hood design; maximum pool elevation

Greater amounts of scour downstream could be expected if the jet has converged.

36. The 1 ft-9 in. backslash plate moved 4 ft downstream was selected by the Sacramento District for placement on the prototype low-level valves. Average pressures on the hood of the low-level outlet works were measured for this design. Locations of the piezometers and the valves observed are shown in Plate 41c. Negative pressures observed at location K are above the range of pressures that indicate the likelihood of cavitation in the prototype.

37. The original hood design (Plate 42) for the FC&I valves was tested at various combinations of percent opening and head on the valve and all tests exhibited excessive backslash (Figure 12). The backslash plate was moved to several alternate locations and good performance was obtained for the lower valve openings but excessive backslash resulted at the larger valve openings.

38. The segmented cone that was developed for the low-level hood was placed on the FC&I hood in an attempt to reduce the backslash with the FC&I hood to an acceptable level. This design is shown in Plate 42 and the resulting backslash at a 32.4-in. sleeve travel is shown in Figure 13. While the backslash with the segmented cone is greater with the FC&I hood than with the low-level hood, the performance was considered acceptable. Because of economics and ease of construction, a modified segmented cone design was selected by the Sacramento District for placement on the prototype FC&I valve hoods that will be continuous rather than segmented; however, the model results are considered valid.

39. Piezometer locations and pressures observed for various combinations of head and valve opening with the segmented cone hood in the FC&I outlet system are shown in Plate 42. These pressures may be of interest relative to the structural design of the FC&I hood. Negative pressures observed at location E for sleeve travels of 16.6- and 11.3-in. (40 and 25 percent valve openings) are on the borderline of the range of pressures that indicate the likelihood of cavitation in the prototype. However, the flow should be highly aerated and this reduces the likelihood for any severe damage of the hood due to cavitation.



Figure 12. FC&I model, original hood design; maximum pool elevation



Figure 13. FC&I model, segmented cone hood design; maximum pool elevation

40. The mean velocity of flow exiting the hoods was determined for a full range of head on the fixed-cone valves and can be described by the equation

$$V = 0.77 \sqrt{2g H_{\text{net}}}$$

for the low-level outlet works with the revised backslash plate location and by the equation

$$V = 0.84 \sqrt{2g H_{\text{net}}}$$

for the FC&I outlet works with the segmented cone hood design. The equations can be used for predicting the profile of the jet as it exits the hoods. This will aid in the design of the splash pads used downstream of the valves.

PART IV: DISCUSSION OF RESULTS AND CONCLUSIONS

41. The fixed-cone valves at the New Melones Dam outlet works exhibited slightly higher discharge coefficients than conventional fixed-cone valves. This is due to the absence of a center hub or cone and connecting vane configuration, which reduce the flow area and increase losses in conventional fixed-cone valves.

42. The design pressures obtained in the New Melones valves were considerably larger than values obtained in prototype tests conducted at Summersville Dam, West Virginia. The Summersville fixed-cone valves were conventional six-vaned Howell Bunger valves. An 11.0-ft-diam butterfly valve was installed 18 ft upstream of the 106.75-in.-diam fixed-cone valves. Under Summersville test conditions of an 80 percent valve opening and $H_{net} = 180.0$ ft, the maximum pressure differential was about 7 psi. For the 66-in.-diam fixed-cone valves at New Melones Dam, test conditions of 27.7-in. sleeve travel (85 percent) and $H_{net} = 147$ ft resulted in maximum differential pressures of 58.8 psi. For the 78-in.-diam fixed-cone valves, test conditions of 32.4-in. sleeve travel (85 percent) and $H_{net} = 561$ ft resulted in a maximum differential pressure of 56.1 psi. The greater pressure differentials obtained for the 66-in.-diam valves at New Melones Dam are caused by the combined bends which impart a significant fluctuation of flow just upstream of the valves. The greater differentials obtained for the 78-in.-diam valves are caused by a combination of the instability generated at the upstream bifurcation and the higher velocities that occur in the FC&I outlet works.

43. The maximum differential pressures determined from both models were used in the structural analysis of the valves. This analysis was conducted by contractors to the Sacramento District and involved a finite-element structural model to determine the maximum stresses induced by flow through the valves. Results of the analysis determined that the stress limits established in the contract specifications were exceeded and that strengthening of the vanes was necessary to ensure the structural integrity of the valves. Rather than

increasing the thickness of the vanes and possibly affecting flow characteristics of the valves, the steel was changed to a higher grade steel having a yield stress of 100 ksi. The resulting stresses as determined in the finite-element analysis were within the contract specifications.

44. Results obtained from this study are valid for use in designing against fatigue failure of the vanes of the fixed-cone valves. Although amplitude spectra developed from time-histories of pressure, strain, and dye injections determined that predominant frequencies were low and that very little energy was present at high frequencies, the possibility of an interaction between the structure and the fluid resulting in a resonant failure cannot be ruled out. This fluid-structure interaction cannot be addressed in a "stiff" hydraulic model valve study. Therefore, prototype tests of the New Melones valves are planned to address the fluid-structure interaction and obtain model-prototype correlation. Pressure transducers, strain gages, and accelerometers will be installed in the prototype valves to detect any resonant conditions or fluid-structure interactions. The prototype pressure transducers have been installed in the same locations as in the model, and test conditions will be as close as possible so that direct comparisons can be made between model and prototype. Results will be published in a future WES technical report.

45. Based on model results, no low-pressure zones were found in the approach conduits of the low-level or FC&I outlet works. The high static pressure in the approach conduits reduces the likelihood of cavitation but the potential for cavitation damage exists, particularly in the FC&I valves where velocities exceed 140 fps under maximum pool conditions. The 4,000-cfs limit of observed nonfluctuating flow found by observing dye injected into the FC&I valve model may be a good maximum flow limit to recommend for use in the operations manual in order to reduce the velocities to about 65 fps and lower the potential for cavitation.

46. The pressure measurements made in the upstream bifurcation were inconclusive as to the location and cause of the instability of flow leaving the upstream bifurcation. Although the predominant

frequency of pressure fluctuations measured in the model below the 9- and 16-in.-diam structural posts were low (2 to 4 Hz) relative to the estimated lowest natural frequency of the posts (40 to 50 Hz), again, the possibility of a resonant condition cannot be ruled out and these posts should be inspected regularly to detect any problems.

47. The revised backsplash plate hood design was selected for use in the prototype low-level outlet works even though it resulted in some backsplash on the valve. This decision was based on economic considerations and the proposed operational schedule which specifies only limited use of the low-level outlet works. Since the FC&I outlet works may receive greater use, the Sacramento District selected the segmented cone design for installation in the prototype. Although the segmented cone did not eliminate the backsplash in the FC&I works, the levels obtained were considered acceptable. Pressures observed in the hoods indicate that cavitation should not occur in the low-level hoods but were borderline in the case of the FC&I hoods. The highly aerated flow, however, should reduce the likelihood for severe cavitation damage.

Table 1
Digitized Time-History of Pressure, Low-Level Outlet Works

Time, Sec	Pressure, Feet of Water		
	I_D	I'_D	$I_D - I'_D$
4.01	92.5	62.1	30.4
4.02	99.7	54.2	45.5
4.03	103.5	50.4	53.1
4.04	102.5	52.7	49.8
4.05	98.8	48.4	50.8
4.06	101.8	52.8	49.0
4.07	94.6	51.3	43.3
4.08	98.0	47.7	50.3
4.09	93.4	54.2	39.2
4.10	95.9	50.0	45.9
4.11	97.4	47.6	49.8
4.12	99.4	48.3	51.1
4.13	103.6	42.5	61.1
4.14	102.5	48.9	53.6
4.15	99.0	39.9	59.1
4.16	105.2	40.6	64.6
4.17	100.1	43.8	56.3
4.18	101.2	40.2	61.0
4.19	99.8	44.6	55.2
4.20	106.6	40.3	66.6
4.21	111.2	44.5	66.7
4.22	103.9	48.8	55.1
4.23	106.6	52.8	53.8
4.24	111.4	49.9	61.5
4.25	118.6	48.8	69.8
4.26	118.7	40.5	78.2
4.27	114.9	38.7	76.2
4.28	106.7	40.6	66.1
4.29	106.0	44.2	61.8
4.30	112.1	42.1	70.0
4.31	126.2	35.3	90.9
4.32	120.1	37.5	82.6
4.33	127.0	40.9	86.1
4.34	121.2	40.3	80.9
4.35	120.7	48.2	72.5
4.36	111.4	52.8	58.6
4.37	110.4	56.7	53.7
4.38	118.4	48.6	69.8
4.39	125.3	43.5	81.8
4.40	119.0	49.2	69.8
4.41	109.7	44.6	65.1
4.42	111.0	45.7	65.3

(Continued)

Table 1 (Concluded)

Time, Sec	Pressure, Feet of Water		
	I_D	I'_D	$I_D - I'_D$
4.43	114.5	61.8	52.7
4.44	113.5	42.9	70.6
4.45	118.0	45.9	72.1
4.46	115.6	52.6	63.0
4.47	112.6	41.9	70.7
4.48	118.0	38.9	79.1
4.49	129.7	34.5	95.2
4.50	133.9	30.7	103.2*
4.51	132.1	35.9	96.2

NOTE: Master Vane: 10:30

Test #115

HNET = 147 ft

Valve Opening = 85%

Sleeve Travel = 27.7 in.

* Maximum differential pressure.

Table 2
Digitized Time-History of Pressure
Flood Control and Irrigation Outlet System

<u>Time, Sec</u>	<u>Pressure, Feet of Water</u>		
	I_D	I'_D	$I_D - I'_D$
1.51	233.4	202.0	31.5
1.52	238.4	207.5	30.9
1.53	239.7	205.5	34.2
1.54	238.8	204.3	34.5
1.55	246.7	200.6	46.1
1.56	248.6	199.7	49.0
1.57	247.0	191.2	55.8
1.58	248.7	190.2	58.6
1.59	248.9	183.0	65.9
1.60	249.8	179.1	70.7
1.61	258.2	177.2	81.0
1.62	259.4	172.6	86.8
1.63	260.0	169.3	90.7
1.64	254.9	168.9	86.0
1.65	259.2	171.0	88.2
1.66	258.2	171.6	86.5
1.67	268.0	163.2	104.8
1.68	265.5	164.9	100.6
1.69	263.3	161.7	101.6
1.70	269.1	164.4	104.6
1.71	272.9	161.4	111.5
1.72	270.9	168.3	102.6
1.73	276.5	168.0	108.6
1.74	280.1	164.4	115.6
1.75	276.0	158.8	117.2
1.76	280.6	160.0	120.6
1.77	277.3	158.9	118.4
1.78	272.7	160.2	112.6
1.79	282.4	152.9	119.5
1.80	284.4	154.9	129.4*
1.81	279.0	160.2	118.9
1.82	274.4	168.7	105.7
1.83	261.9	188.2	73.7
1.84	254.4	202.3	52.1
1.85	253.5	212.2	41.3
1.86	245.1	201.6	43.4
1.87	245.9	202.7	43.1
1.88	247.2	205.0	42.2

(Continued)

* Maximum differential pressure.

Table 2 (Concluded)

Time, Sec	Pressure, Feet of Water		
	I_D	I'_D	$I_D - I'_D$
1.89	248.7	201.3	47.4
1.90	236.7	203.5	33.2
1.91	244.0	194.3	49.7
1.92	240.0	191.7	49.7
1.93	240.5	188.2	58.3
1.94	244.2	191.1	53.1
1.95	242.7	189.2	53.5
1.96	243.4	194.8	48.6
1.97	240.1	193.1	47.0
1.98	241.9	197.5	44.4
1.99	239.7	190.8	48.9
2.00	241.9	194.3	47.6

NOTE: Master Vane: 6:00
 Test #522
 HNET = 561.0 ft
 Valve Opening = 85%
 Sleeve Travel = 32.4 in.

Table 3
One-Valve Time-History of Pressure Operation
Flood Control and Irrigation Outlet System

Time Sec	Pressure, Feet of Water					
	I_B	I'_B	$I_B - I'_B$	I_D	I'_D	$I_D - I'_D$
1.01	149.6	67.4	82.2	217.8	151.2	66.5
1.02	146.2	66.9	79.2	211.2	152.1	59.1
1.03	152.7	68.1	84.6	206.2	167.5	38.7
1.04	153.3	71.0	82.3	208.4	171.1	37.4
1.05	144.4	61.4	83.0	206.8	164.8	42.0
1.06	154.6	66.6	88.0	218.1	155.9	62.2
1.07	155.1	62.9	92.2	221.6	154.8	66.8
1.08	159.3	67.7	91.6	211.1	162.3	48.8
1.09	152.3	70.4	81.8	209.3	158.2	51.1
1.10	143.5	69.1	74.4	218.2	154.8	63.4
1.11	152.4	66.5	85.9	229.9	144.6	85.3
1.12	162.2	65.5	96.8	234.9	144.4	90.5
1.13	156.6	63.6	93.0	207.1	151.9	55.2
1.14	154.3	66.8	87.6	203.2	146.1	57.0
1.15	145.3	62.7	82.5	219.0	155.3	63.6
1.16	137.7	60.7	77.0	238.9	155.3	83.5
1.17	149.9	65.5	84.4	210.8	148.1	62.6
1.18	159.4	72.9	86.5	219.4	155.1	64.3
1.19	154.1	64.7	89.3	207.1	156.2	50.9
1.20	147.8	67.4	80.4	206.7	157.3	49.3
1.21	148.5	67.5	81.0	208.1	156.2	51.9
1.22	143.8	64.3	79.5	212.5	156.5	56.0
1.23	147.6	69.1	78.5	222.3	167.7	54.7
1.24	147.9	68.4	79.6	177.6	167.2	10.3
1.25	135.1	62.7	72.4	208.7	157.3	51.4
1.26	132.0	65.5	66.5	208.3	156.5	51.8
1.27	139.7	65.5	74.3	194.5	153.1	41.5
1.28	148.1	68.1	80.0	200.7	164.0	36.7

(Continued)

Master Vane: 6:00
 Test # 614
 $H_{net} = 561$ ft
 Sleeve travel = 32.4 in.

Table 3 (Concluded)

Time Sec	Pressure, Feet of Water					
	I_B	I'_B	$I_B - I'_B$	I_D	I'_D	$I_D - I'_D$
1.29	154.5	66.6	87.9	211.6	161.4	50.2
1.30	142.1	67.4	74.8	195.4	164.7	30.7
1.31	147.2	63.9	83.3	202.6	167.5	35.1
1.32	151.2	66.2	85.0	208.3	165.3	43.0
1.33	147.6	63.4	84.2	217.8	165.3	52.5
1.34	143.0	67.5	75.5	214.3	161.9	52.4
1.35	153.8	64.9	88.9	211.2	168.5	42.7
1.36	145.7	67.4	78.3	211.2	158.6	52.6
1.37	155.4	69.0	86.4	227.2	158.2	69.0
1.38	154.3	71.0	83.4	217.6	161.9	55.8
1.39	153.5	72.9	80.6	218.2	162.4	55.8
1.40	148.7	70.4	78.3	190.6	154.6	35.9
1.41	147.9	67.2	80.7	191.0	157.6	33.4
1.42	149.7	69.7	80.0	209.2	159.9	49.3
1.43	151.2	66.1	85.2	200.1	153.1	47.0
1.44	153.9	62.3	91.6	210.9	157.5	53.4
1.45	147.0	64.3	82.7	216.8	160.4	56.3
1.46	156.9	64.2	92.7	220.1	168.9	51.2
1.47	152.7	68.2	84.5	222.3	169.2	53.1
1.48	158.1	67.5	90.6	200.1	165.1	35.0
1.49	152.1	65.3	86.8	201.1	168.7	32.5
1.50	152.9	64.7	88.1	216.6	167.1	49.5

Table 4
Approach Conduit Pressures, Low-Level Outlet Works

Piezometer No.	Static Pressure, Feet of Water			
	Sleeve Travel = 27.7 in. Q = 1730 cfs	Sleeve Travel = 20.2 in. Q = 1590 cfs	Sleeve Travel = 14.2 in. Q = 1340 cfs	Sleeve Travel = 9.7 in. Q = 1050 cfs
500	127.0	210.0	308.0	422.0
502	130.0	212.0	311.0	425.0
504	127.0	210.0	308.0	422.0
506	124.0	206.0	305.0	419.0
508	125.0	210.0	308.0	422.0
510	130.0	211.0	312.0	427.0
512	125.0	208.0	319.0	424.0
514	120.0	202.0	304.0	419.0
516	95.0	181.0	288.0	409.0
518	85.0	173.0	282.0	406.0
520	86.0	175.0	282.0	407.0
522	98.0	182.0	288.0	410.0
524	95.0	181.0	287.0	407.0
526	95.0	180.0	287.0	406.0
528	98.0	182.0	287.0	407.0
530	107.0	193.0	294.0	409.0
532	107.0	191.0	292.0	410.0
534	109.0	193.0	295.0	412.0
536	104.0	188.0	289.0	408.0
538	108.0	192.0	294.0	410.0
540	107.0	190.0	290.0	409.0
542	67.0	155.0	265.0	389.0
544	71.0	160.0	270.0	392.0
546	71.0	160.0	269.0	394.0
548	67.0	157.0	265.0	389.0
550	71.0	160.0	269.0	394.0
552	66.0	156.0	266.0	392.0
554	72.0	157.0	269.0	392.0
556	72.0	160.0	266.0	389.0
558	73.0	160.0	269.0	390.0
560	89.0	174.0	275.0	395.0
562	94.0	178.0	277.0	397.0
564	94.0	179.0	281.0	401.0
566	86.0	170.0	276.0	392.0
568	85.0	170.0	272.0	391.0
570	89.0	173.0	277.0	395.0
572	92.0	176.0	280.0	398.0
574	89.0	174.0	276.0	396.0
576	76.0	162.0	269.0	391.0
578	78.0	166.0	271.0	394.0
580	77.0	162.0	269.0	389.0

Table 5

(Continued)

(Sheet 1 of 4)

Table 5 (Continued)

Parameter No.	Static Pressure, Feet of Water				
	Sleeve Travel = 31.1 in. Q = 7850 cfs	Sleeve Travel = 33.6 in. Q = 8060 cfs	Sleeve Travel = 36.1 in. Q = 8270 cfs	Sleeve Travel = 38.6 in. Q = 8480 cfs	Sleeve Travel = 41.1 in. Q = 8690 cfs
18a	438.0	517.0	560.0	601.0	641.0
18b	415.0	504.0	550.0	594.0	634.0
18c	436.0	504.0	560.0	600.0	646.0
18d	448.0	583.0	651.0	706.0	760.0
19a	464.0	530.0	587.0	646.0	706.0
19b	478.0	546.0	580.0	633.0	680.0
19c	495.0	527.0	561.0	612.0	659.0
19d	495.0	588.0	668.0	715.0	769.0
19e	443.0	517.0	566.0	613.0	661.0
20a	450.0	528.0	566.0	613.0	661.0
20b	446.0	521.0	559.0	607.0	655.0
20c	439.0	511.0	560.0	610.0	658.0
20d	449.0	521.0	562.0	607.0	653.0
20e	442.0	521.0	562.0	607.0	653.0
21a	442.0	514.0	559.0	603.0	648.0
21b	449.0	518.0	565.0	607.0	653.0
21c	446.0	521.0	562.0	607.0	653.0
21d	449.0	521.0	562.0	607.0	653.0
21e	442.0	514.0	559.0	603.0	648.0
22a	449.0	521.0	562.0	607.0	653.0
22b	446.0	510.0	555.0	600.0	645.0
22c	449.0	521.0	562.0	607.0	653.0
22d	449.0	521.0	562.0	607.0	653.0
22e	449.0	521.0	562.0	607.0	653.0
23a	449.0	521.0	562.0	607.0	653.0
23b	449.0	521.0	562.0	607.0	653.0
23c	449.0	521.0	562.0	607.0	653.0
23d	449.0	521.0	562.0	607.0	653.0
23e	449.0	521.0	562.0	607.0	653.0
24a	449.0	521.0	562.0	607.0	653.0
24b	449.0	521.0	562.0	607.0	653.0
24c	449.0	521.0	562.0	607.0	653.0
24d	449.0	521.0	562.0	607.0	653.0
24e	449.0	521.0	562.0	607.0	653.0
25a	449.0	521.0	562.0	607.0	653.0
25b	449.0	521.0	562.0	607.0	653.0
25c	449.0	521.0	562.0	607.0	653.0
25d	449.0	521.0	562.0	607.0	653.0
25e	449.0	521.0	562.0	607.0	653.0
26a	449.0	521.0	562.0	607.0	653.0
26b	449.0	521.0	562.0	607.0	653.0
26c	449.0	521.0	562.0	607.0	653.0
26d	449.0	521.0	562.0	607.0	653.0
26e	449.0	521.0	562.0	607.0	653.0

(Continued)

(Sheet 2 of 4)

Table 5 (Continued)

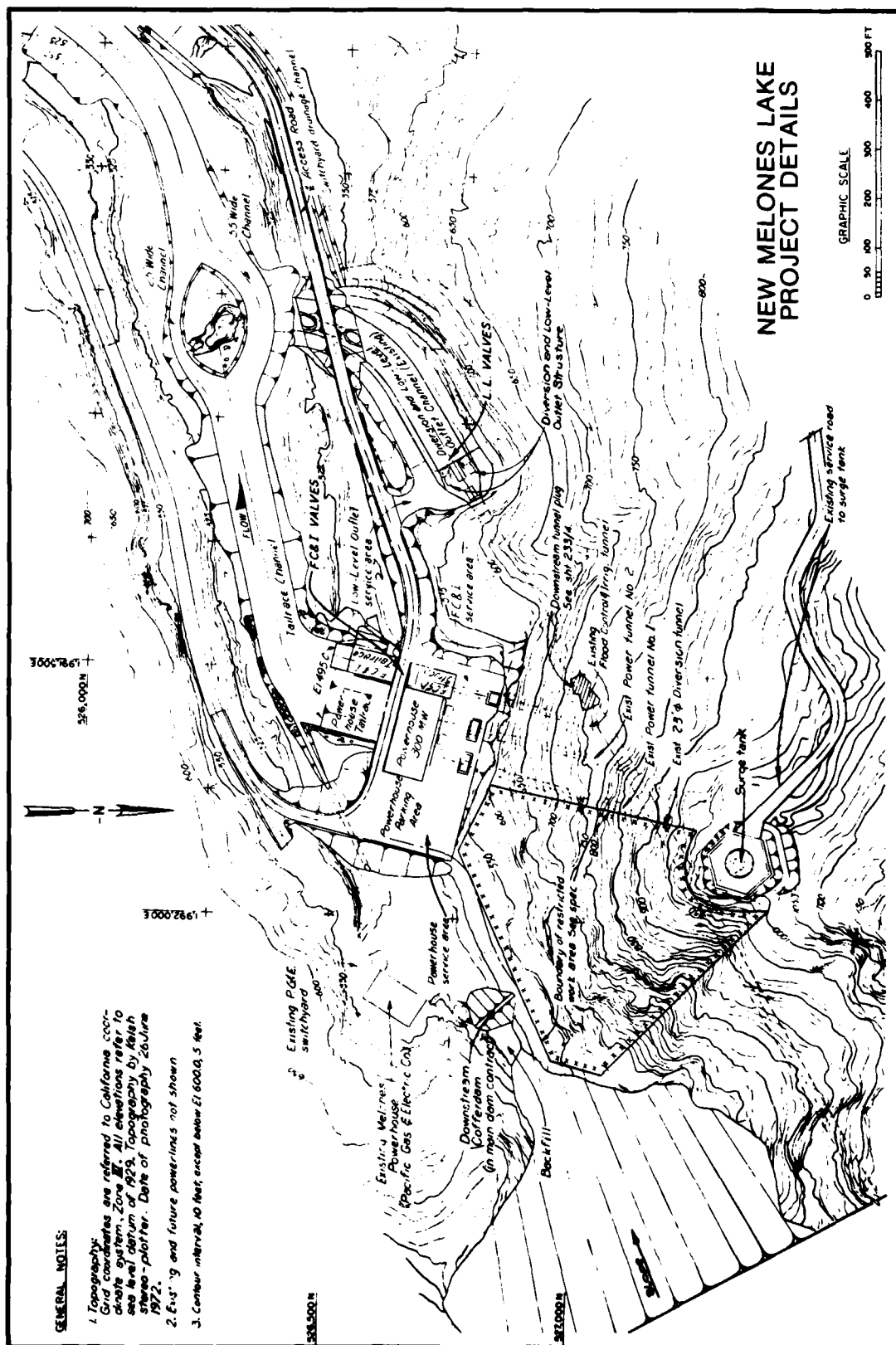
Piezometer No.	Static Pressure, Feet of Water			
	Sleeve Travel = 32.4 In. q = 7890 cfs	Sleeve Travel = 23.6 In. q = 6060 cfs	Sleeve Travel = 16.6 In. q = 3490 cfs	Sleeve Travel = 11.3 In. q = 1910 cfs
266	456.0	317.0	358.0	409.0
268	439.0	310.0	353.0	401.0
270	468.0	328.0	355.0	402.0
272	476.0	336.0	372.0	419.0
274	466.0	327.0	364.0	409.0
276	455.0	323.0	354.0	402.0
278	475.0	333.0	368.0	409.0
280	490.0	336.0	362.0	412.0
282	497.0	346.0	377.0	415.0
284	497.0	349.0	368.0	408.0
286	504.0	350.0	383.0	418.0
288	497.0	336.0	370.0	414.0
290	503.0	353.0	376.0	412.0
292	522.0	354.0	382.0	420.0
294	523.0	368.0	390.0	431.0
296	503.0	353.0	380.0	422.0
298	518.0	369.0	389.0	421.0
300	509.0	339.0	374.0	410.0
302	523.0	359.0	378.0	416.0
304	524.0	359.0	378.0	415.0
306	535.0	365.0	385.2	419.0
310	539.0	363.0	386.0	420.0
312	534.0	363.0	380.0	415.0
314	539.0	375.0	395.0	425.0
316	508.0	371.0	392.0	428.0
318	527.0	368.0	392.0	426.0
320	546.0	378.0	400.0	428.0
322	536.0	375.0	395.0	433.0
326	547.0	376.0	398.0	431.0
328	548.0	376.0	398.0	431.0
330	518.0	354.0	373.0	413.0
332	538.0	364.0	384.0	410.0
336	532.0	359.0	378.0	414.0
338	532.0	346.0	379.0	416.0
340	534.0	365.0	382.0	420.0
342	535.0	364.0	388.0	419.0
344	535.0	358.0	385.0	416.0
346	538.0	364.0	388.0	421.0
348	538.0	369.0	396.0	426.0
350	538.0	369.0	399.0	428.0
352	506.0	359.0	383.0	415.0
354	522.0	342.0	380.0	409.0
356	538.0	365.0	389.0	421.0

(Continued)

(Sheet 3 of 4)

Table 5 (Continued)

Diameter In.	Static Pressure, Feet of Water			
	Sleeve Travel = 21.1 in. Q = 950 cfs	Sleeve Travel = 23.6 in. Q = 1000 cfs	Sleeve Travel = 16.6 in. Q = 570 cfs	Sleeve Travel = 11.3 in. Q = 350 cfs
358	513.0	565.0	569.0	590.0
360	515.0	565.0	568.0	593.0
362	516.0	566.0	568.0	598.0
364	516.0	571.0	590.0	598.0
366	518.0	573.0	593.0	605.0
368	518.0	578.0	593.0	605.0
370	518.0	569.0	593.0	605.0
372	518.0	578.0	595.0	607.0
374	518.0	566.0	595.0	606.0
376	518.0	581.0	595.0	606.0
378	518.0	557.0	595.0	606.0
380	518.0	557.0	595.0	606.0
382	518.0	558.0	595.0	606.0
384	518.0	558.0	595.0	606.0
386	518.0	558.0	595.0	606.0
388	518.0	558.0	595.0	606.0
390	518.0	558.0	595.0	606.0
392	518.0	558.0	595.0	606.0
394	518.0	558.0	595.0	606.0
396	518.0	558.0	595.0	606.0
398	518.0	558.0	595.0	606.0
400	518.0	558.0	595.0	606.0
402	518.0	558.0	595.0	606.0
404	518.0	558.0	595.0	606.0
406	518.0	558.0	595.0	606.0
408	518.0	558.0	595.0	606.0



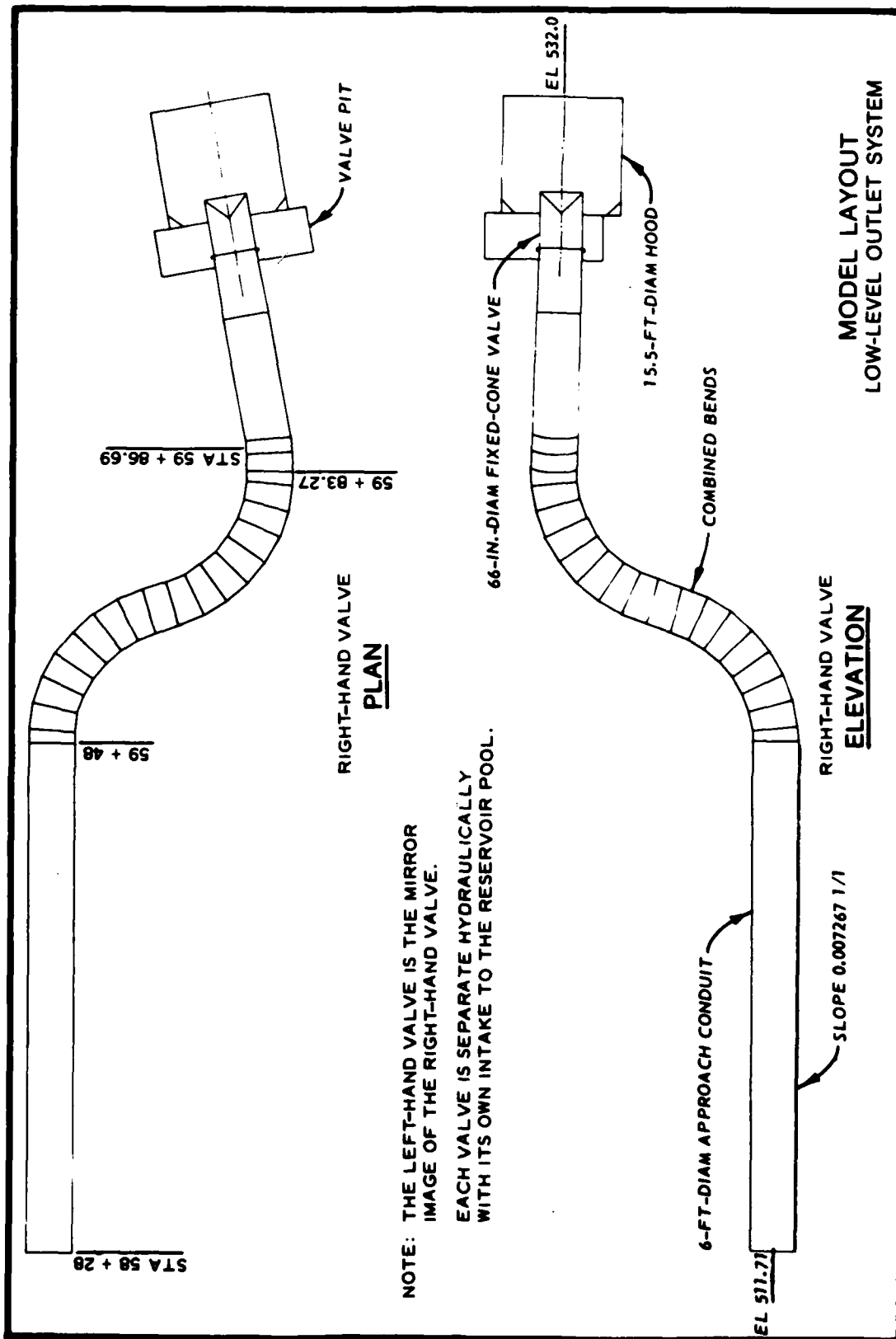
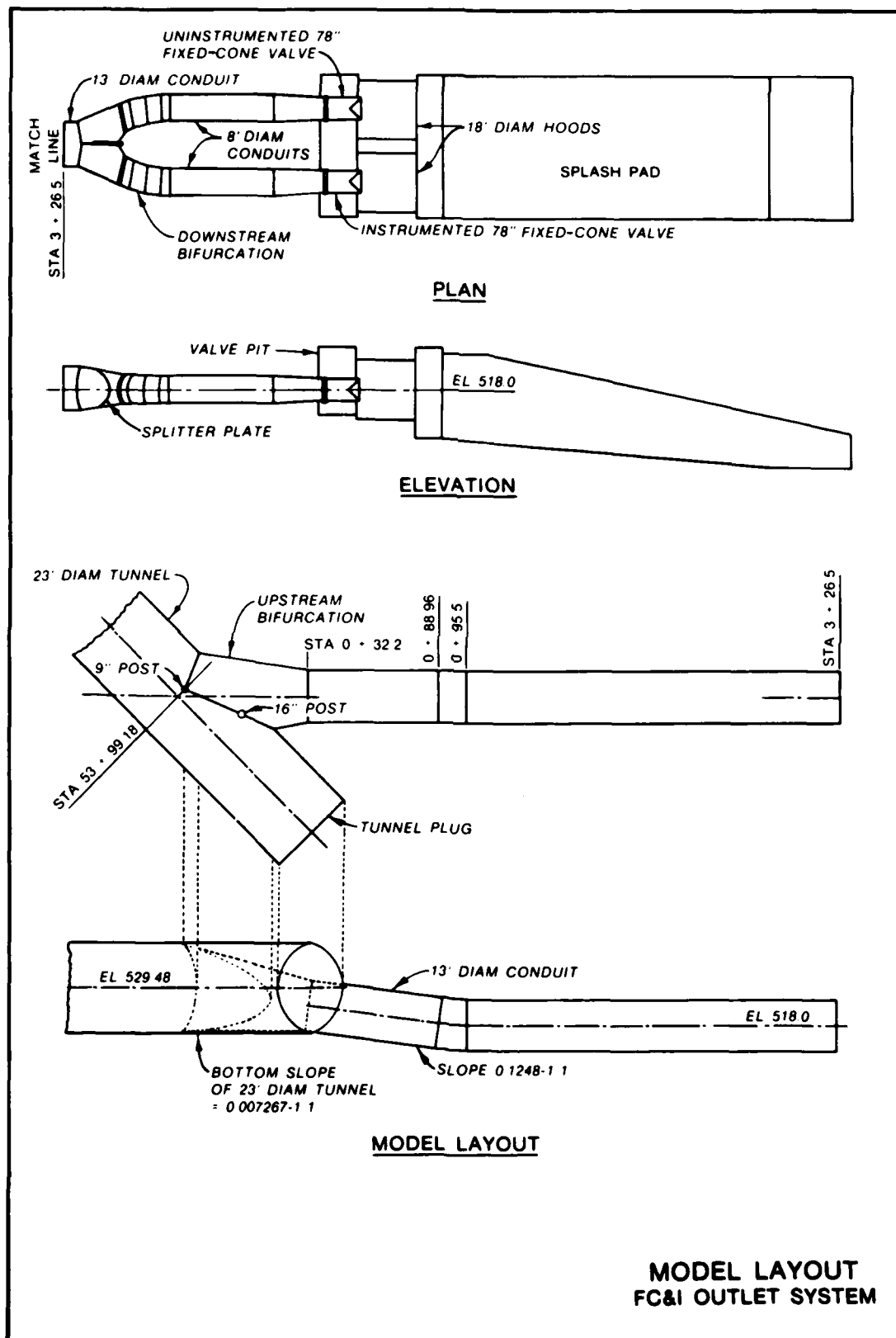
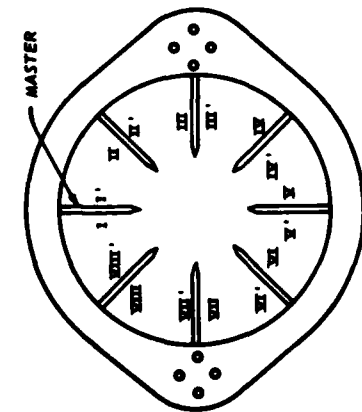
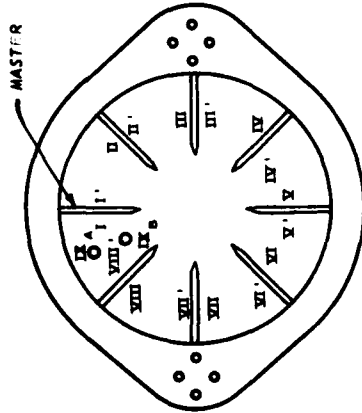


PLATE 2



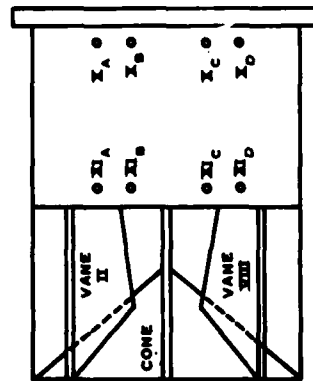


a. VANE LOCATIONS

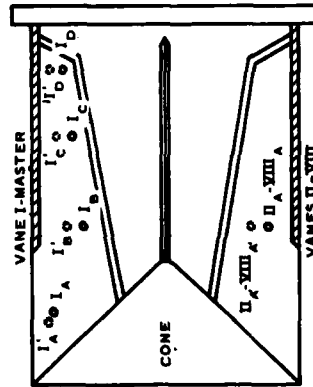


b. CONE TRANSDUCER LOCATIONS

NOTE: VIEW LOOKING DOWNSTREAM

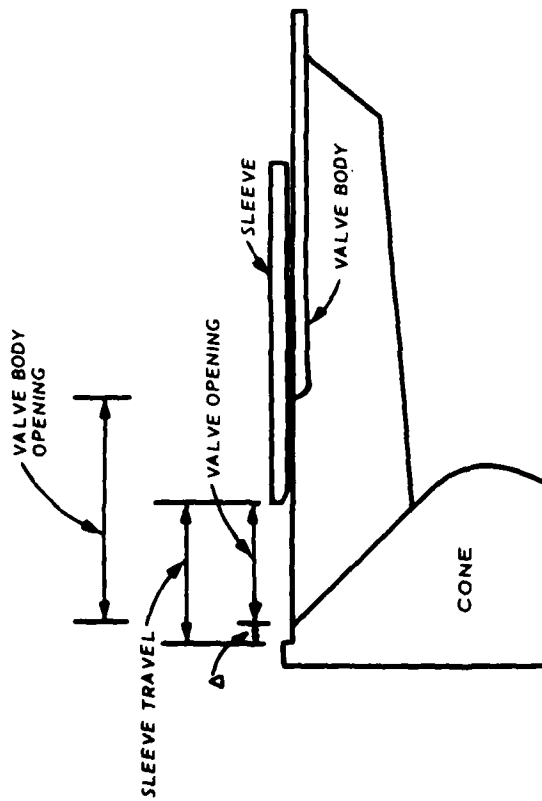


c. VALVE BODY TRANSDUCERS



d. VANE TRANSDUCER LOCATIONS

TRANSDUCER LOCATIONS



VALVE DIMENSIONS:

	FC&I, IN.	LOW-LEVEL, IN.
VALVE DIAMETER	78	66
VALVE BODY OPENING	39.62	33.44
Δ	2.48	2.2

FIXED-CONE VALVE DIMENSIONS

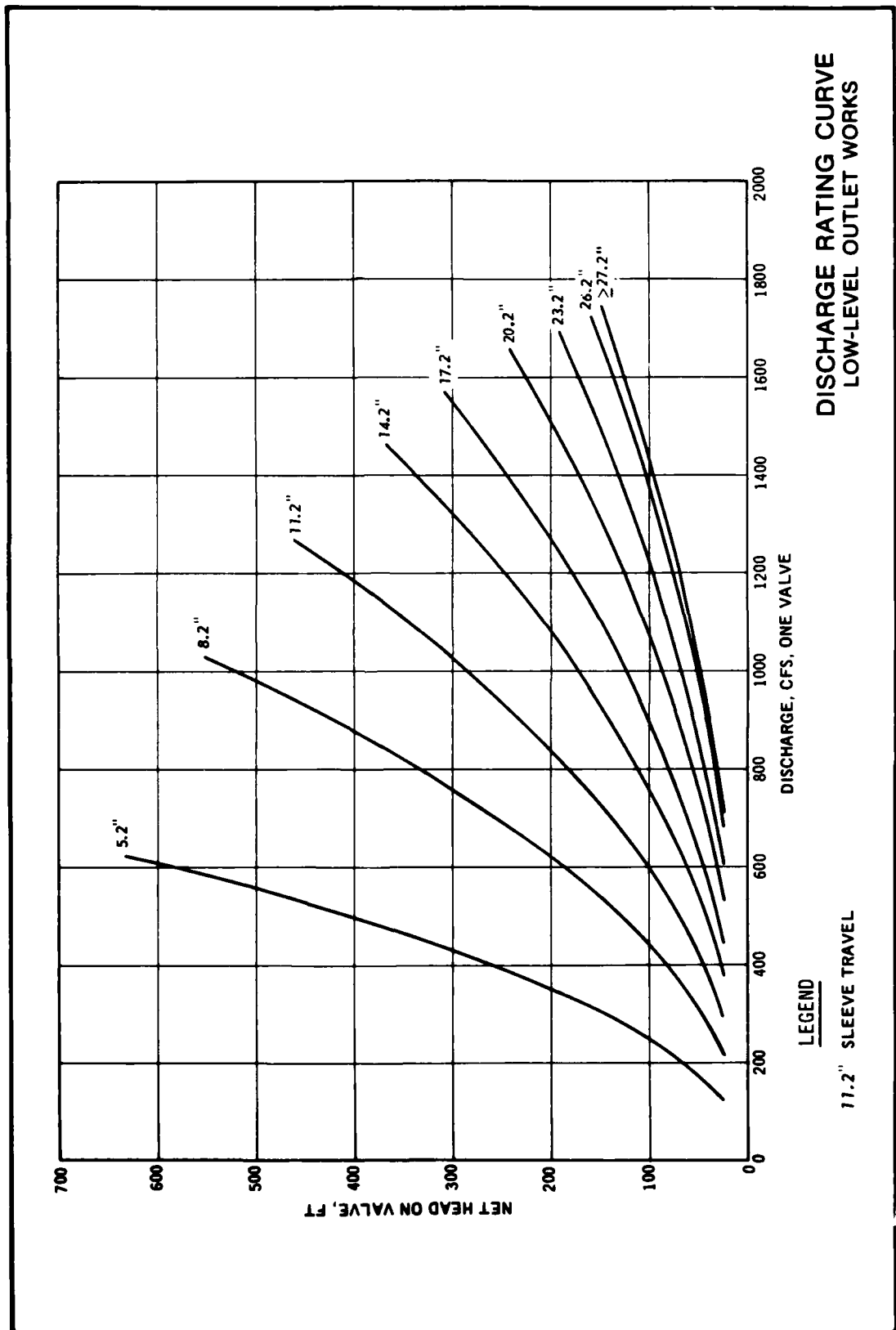
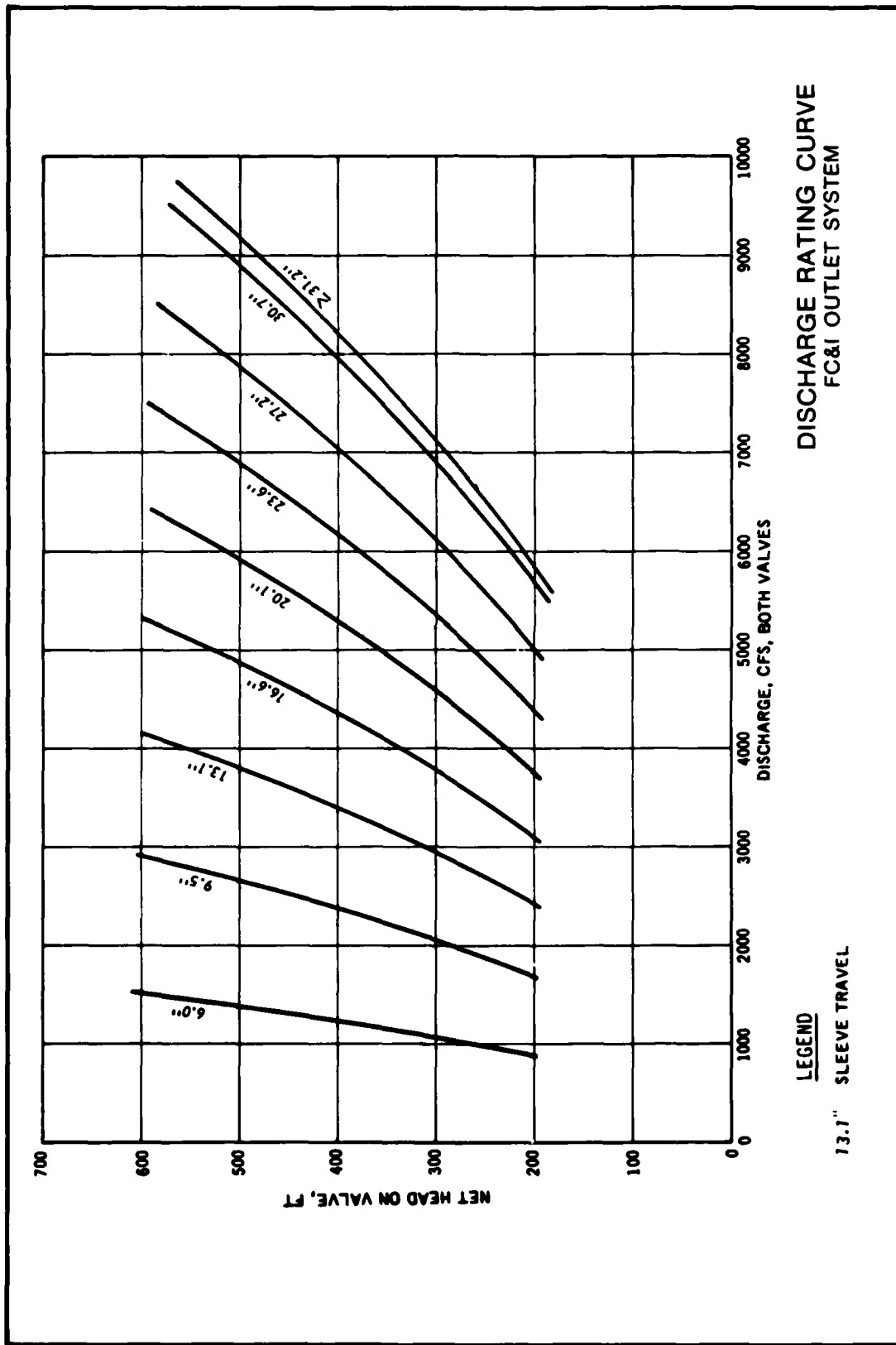
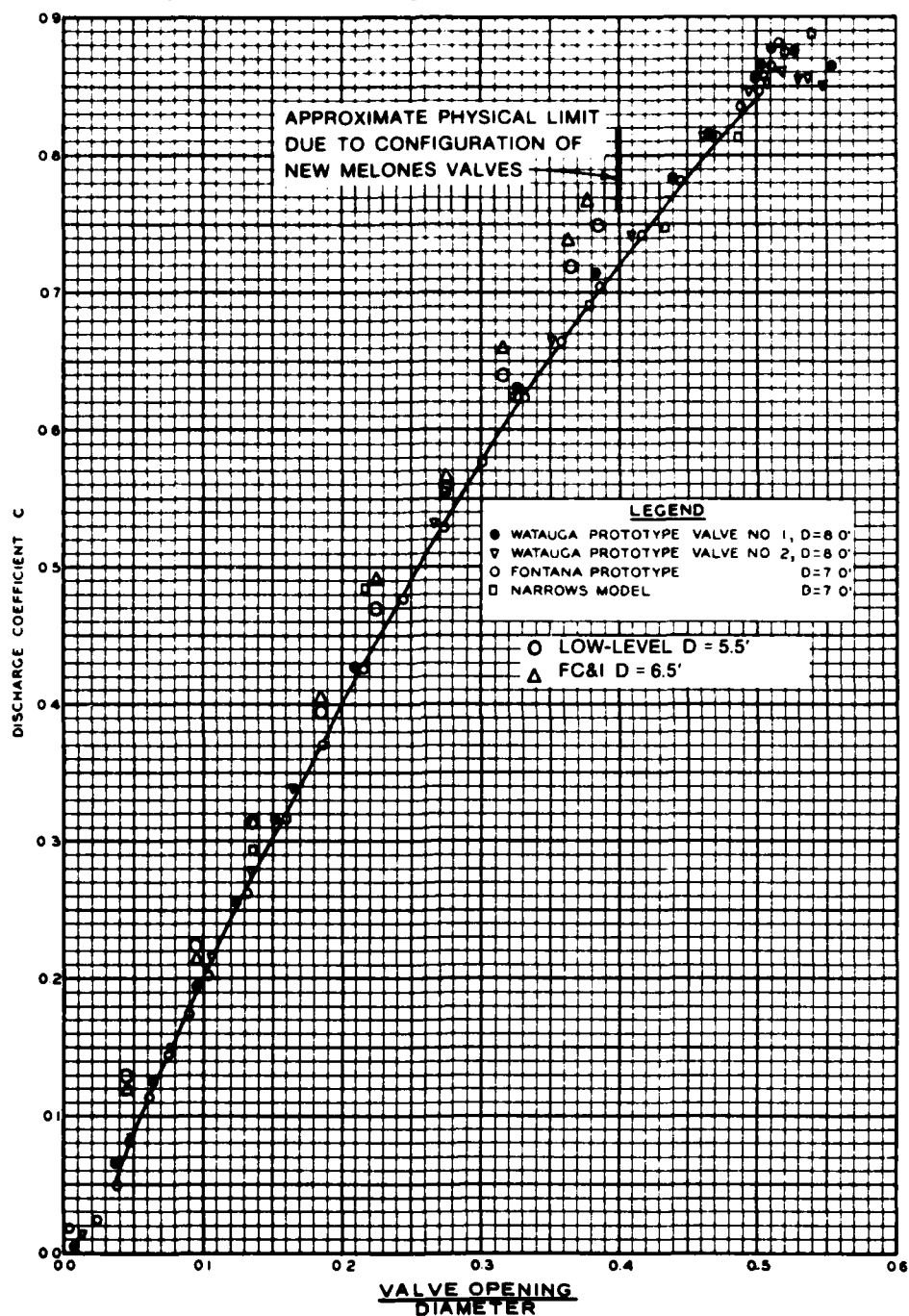


PLATE 6





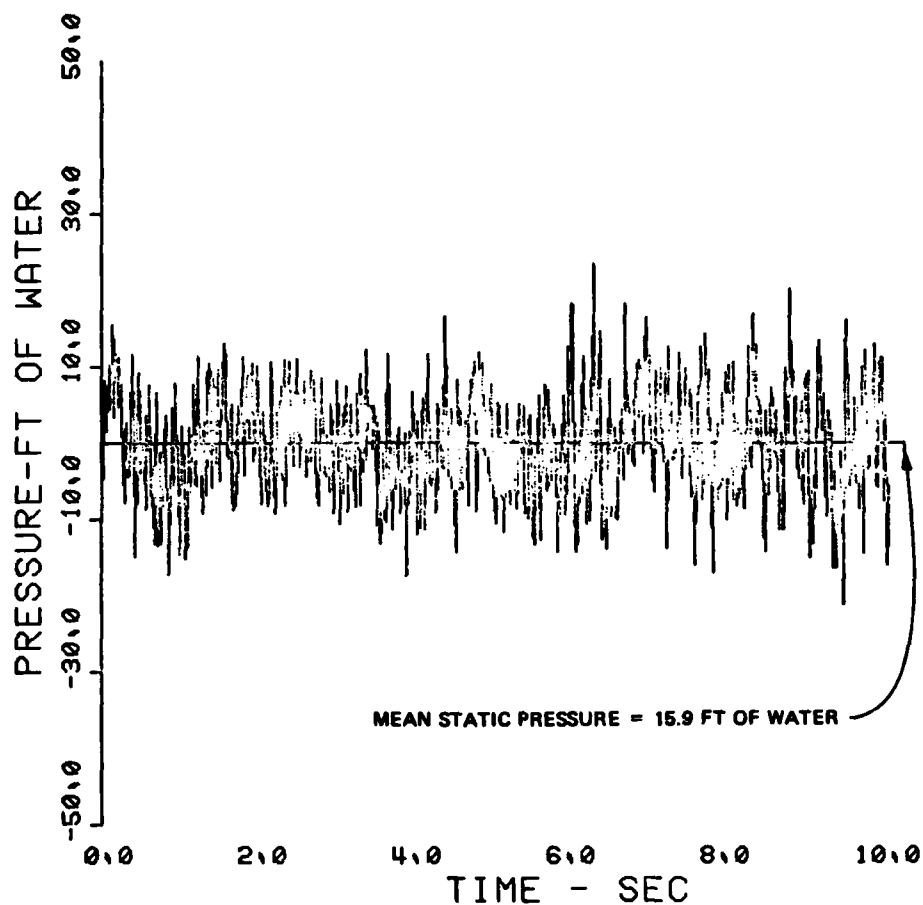
BASIC EQUATION

$$Q = CA\sqrt{2gH_e}$$

WHERE

C=DISCHARGE COEFFICIENT
 A=AREA OF CONDUIT IMMEDIATELY UPSTREAM
 FROM VALVE IN SQ FT
 H_e =ENERGY HEAD MEASURED TO CENTERLINE OF
 CONDUIT IMMEDIATELY UPSTREAM FROM VALVE IN FT

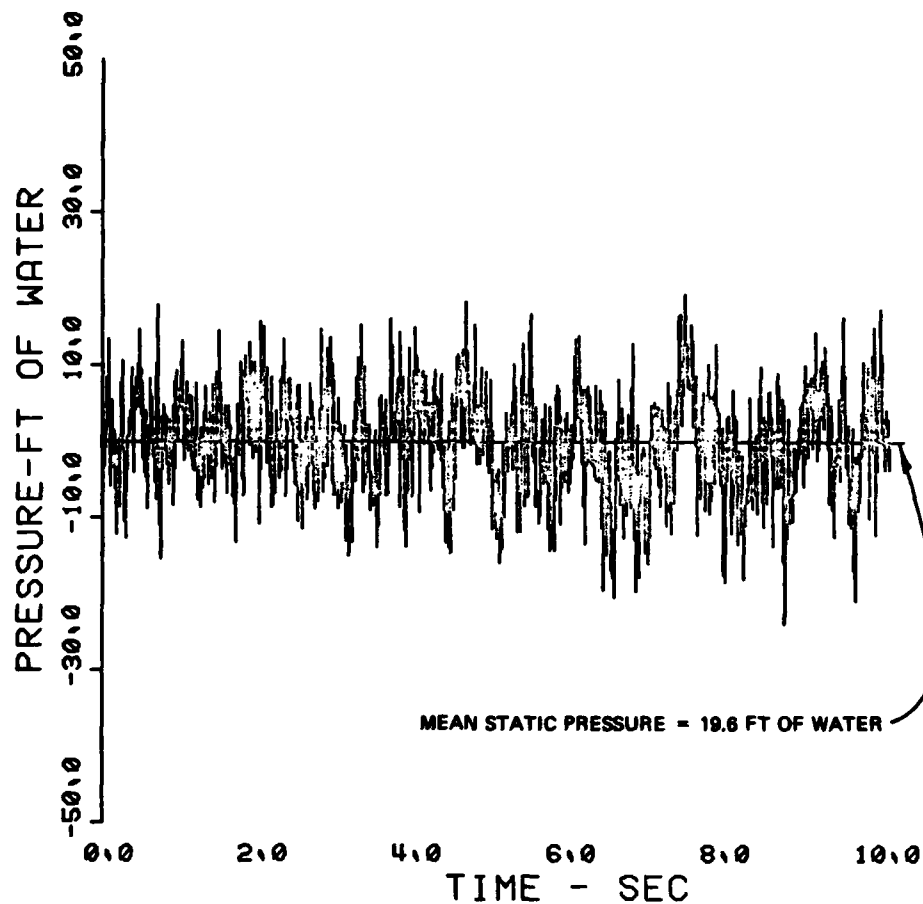
DISCHARGE COEFFICIENTS
 6-VANED HOWELL-BUNGER VALVES
 AND 8-VANED FIXED-CONE
 VALVES (ALTERNATE DESIGN)
 HYDRAULIC DESIGN CHART 332-1/1
 (modified)



LEGEND

MASTER VANE 12:00 O'CLOCK
 NET HEAD 418 FT OF WATER
 SLEEVE TRAVEL 9.7"

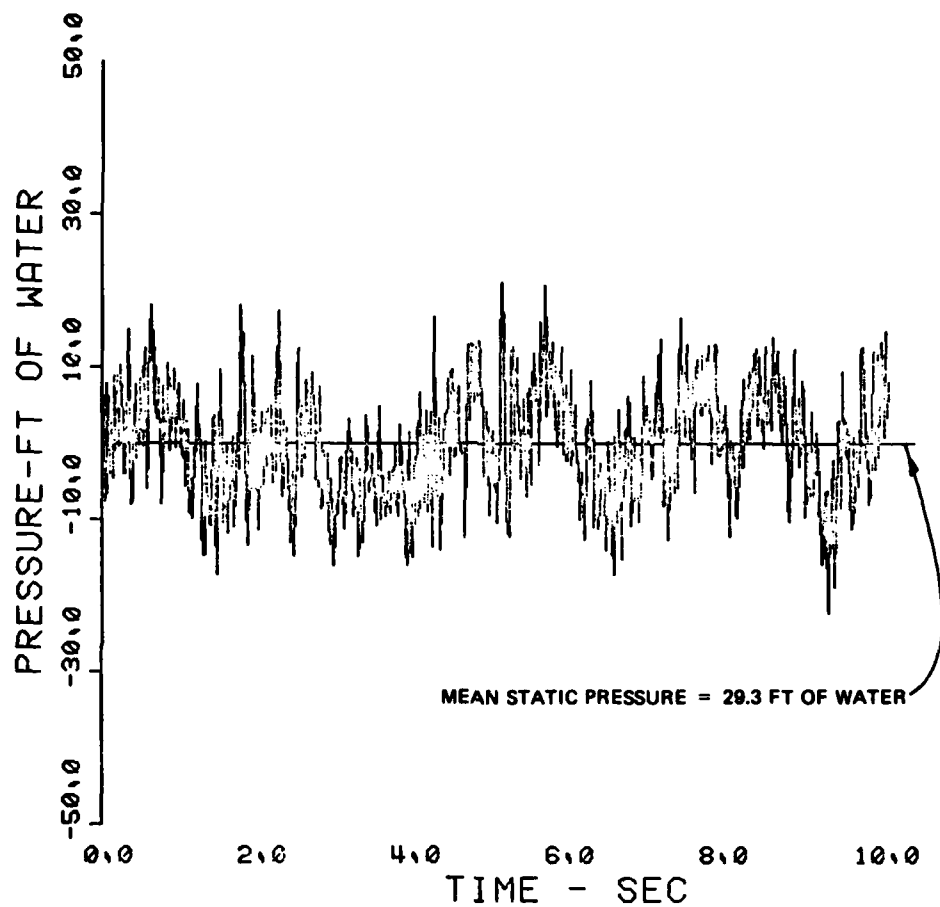
TIME - HISTORY
 LOW-LEVEL OUTLET WORKS
 TEST 126 TRANSDUCERS I-VIII
 INSTANTANEOUS TORQUE ON VALVE



LEGEND

MASTER VANE 12:00 O'CLOCK
 NET HEAD 311 FT OF WATER
 SLEEVE TRAVEL 14.2"

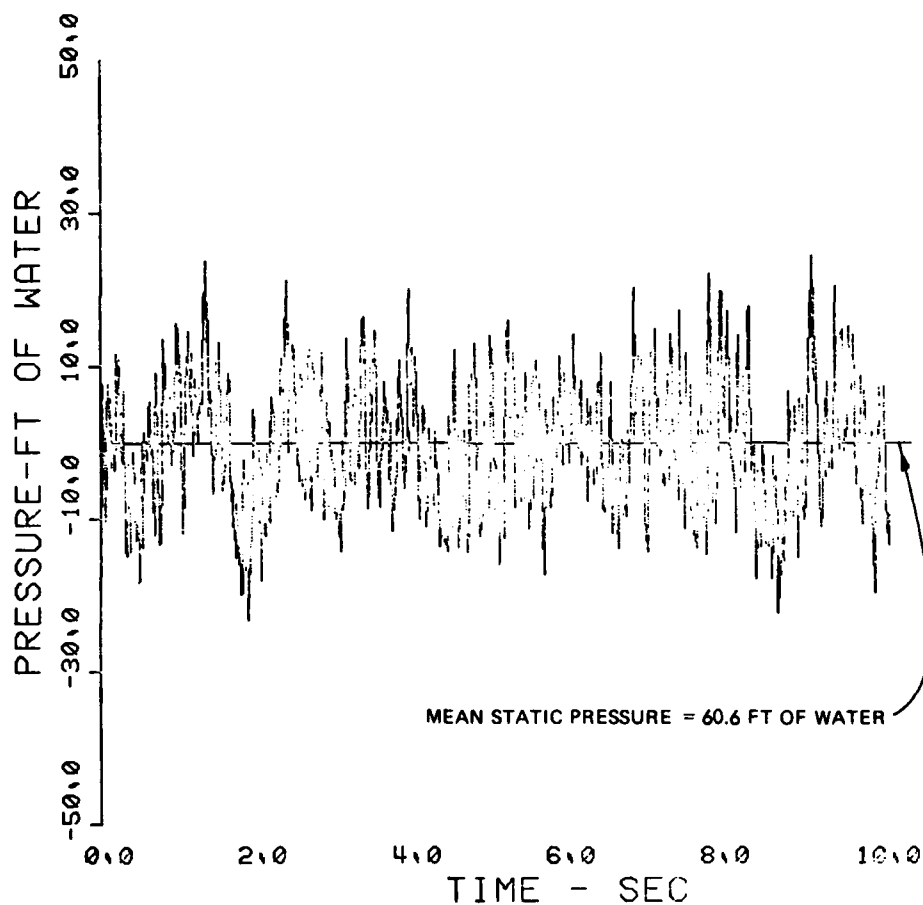
TIME - HISTORY
 LOW-LEVEL OUTLET WORKS
 TEST 125 TRANSDUCERS I-VIII
 INSTANTANEOUS TORQUE ON VALVE



LEGEND

MASTER VANE 12:00 O'CLOCK
 NET HEAD 218 FT OF WATER
 SLEEVE TRAVEL 20.2"

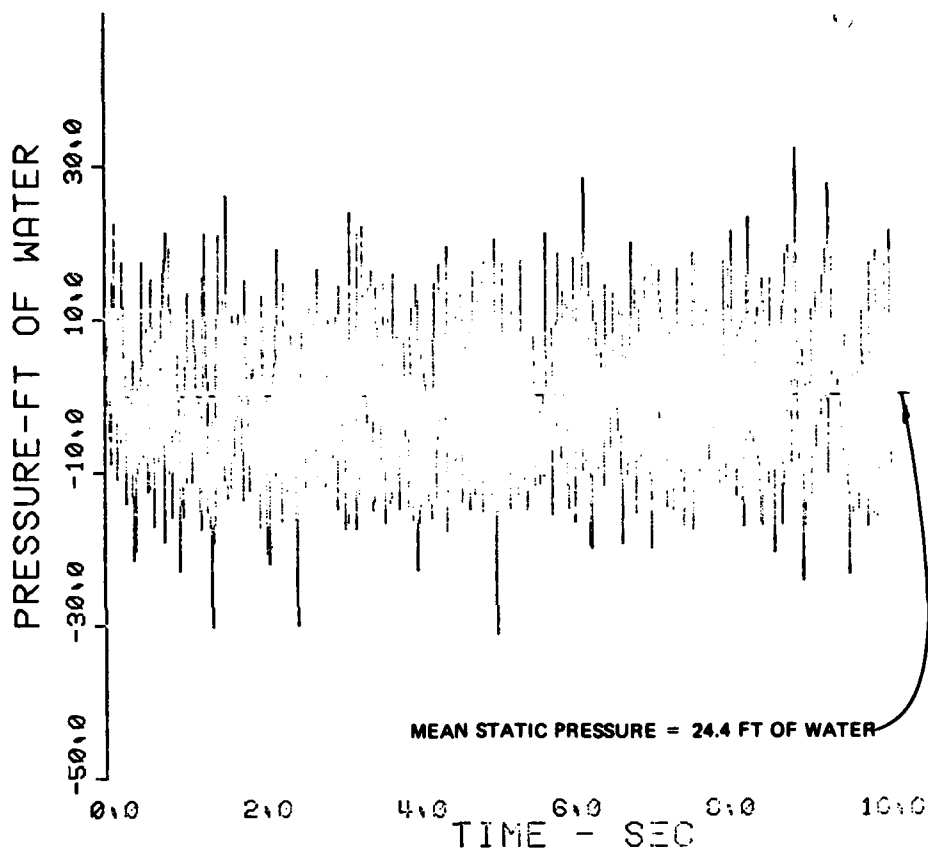
TIME - HISTORY
 LOW-LEVEL OUTLET WORKS
 TEST 132 TRANSDUCERS I-VIII
 INSTANTANEOUS TORQUE ON VALVE



LEGEND

MASTER VANE 12:00 O'CLOCK
 NET HEAD 147 FT OF WATER
 SLEEVE TRAVEL 27.7"

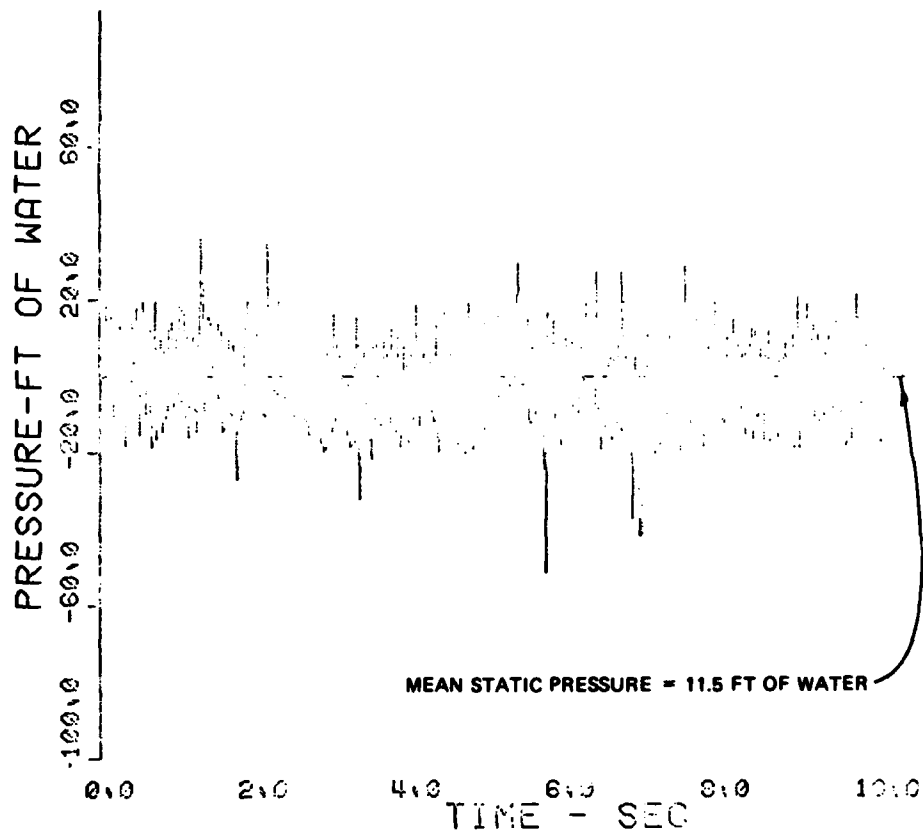
TIME - HISTORY
 LOW-LEVEL OUTLET WORKS
 TEST 134 TRANSDUCERS I-VIII
 INSTANTANEOUS TORQUE ON VALVE



LEGEND

MASTER VANE 12:00 O'CLOCK
 NET HEAD 599 FT OF WATER
 SLEEVE TRAVEL 11.3"

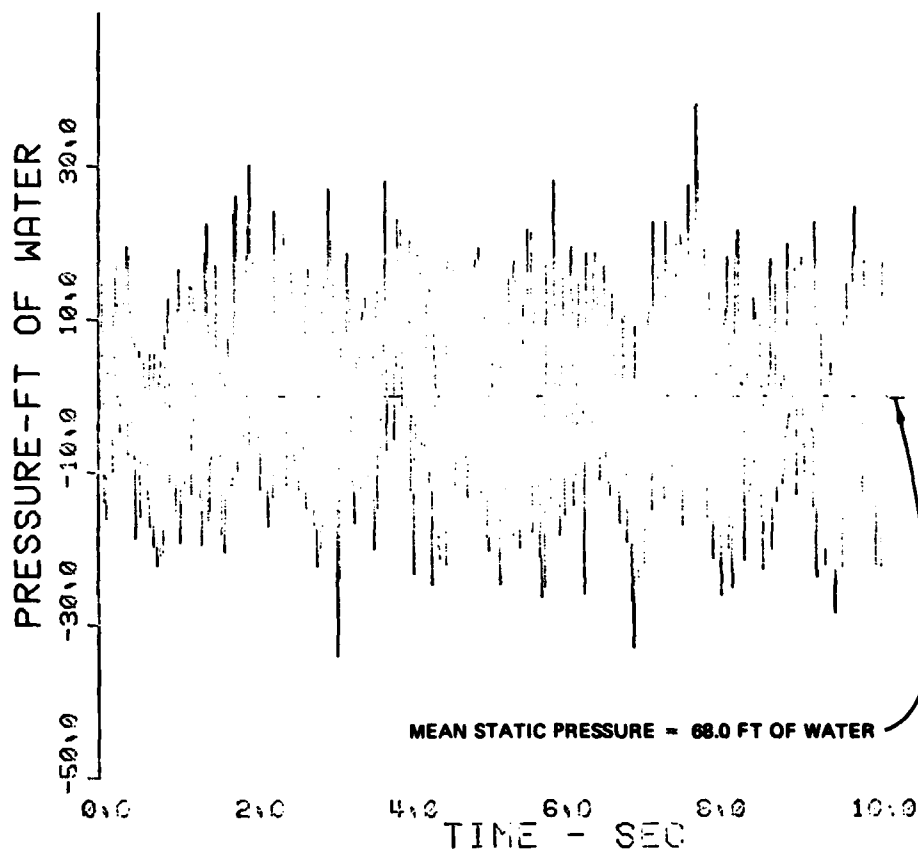
TIME - HISTORY
 FLOOD CONTROL AND IRRIGATION
 OUTLET SYSTEM
 TEST 509 TRANSDUCERS I-VIII
 INSTANTANEOUS TORQUE ON VALVE



LEGEND

MASTER VANE 12:00 O'CLOCK
 NET HEAD 591 FT OF WATER
 SLEEVE TRAVEL 16.6"

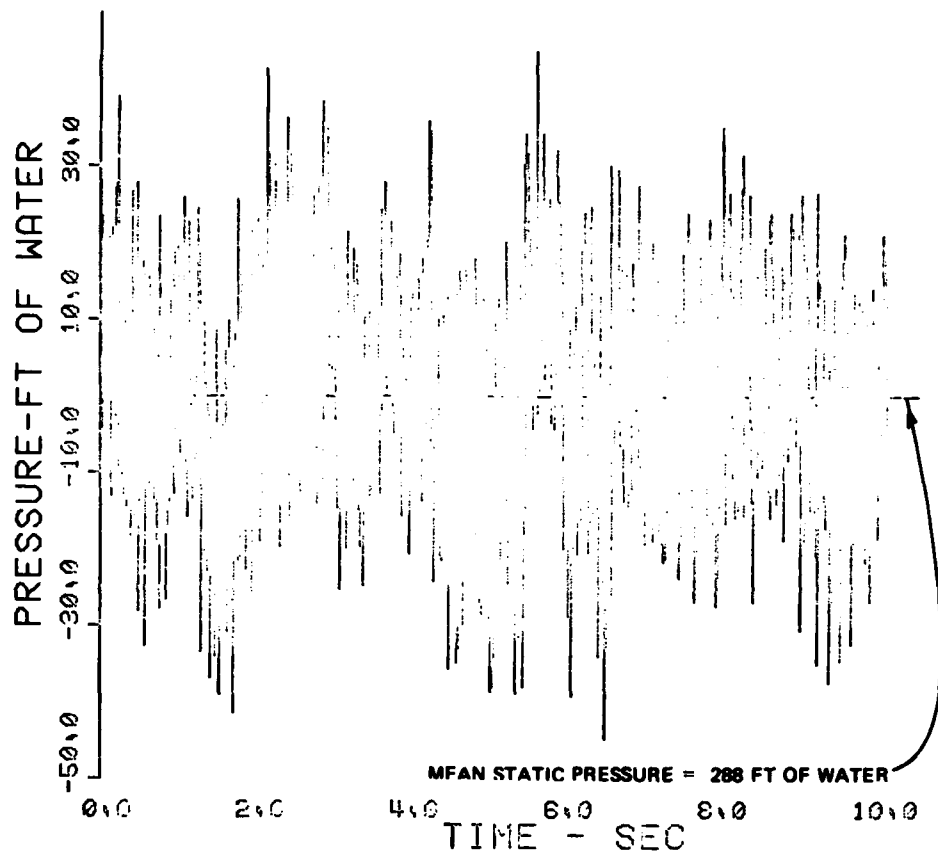
TIME - HISTORY
 FLOOD CONTROL AND IRRIGATION
 OUTLET SYSTEM
 TEST 508 TRANSDUCERS I-VIII
 INSTANTANEOUS TORQUE ON VALVE



LEGEND

MASTER VANE 12:00 O'CLOCK
 NET HEAD 580 FT OF WATER
 SLEEVE TRAVEL 23.6"

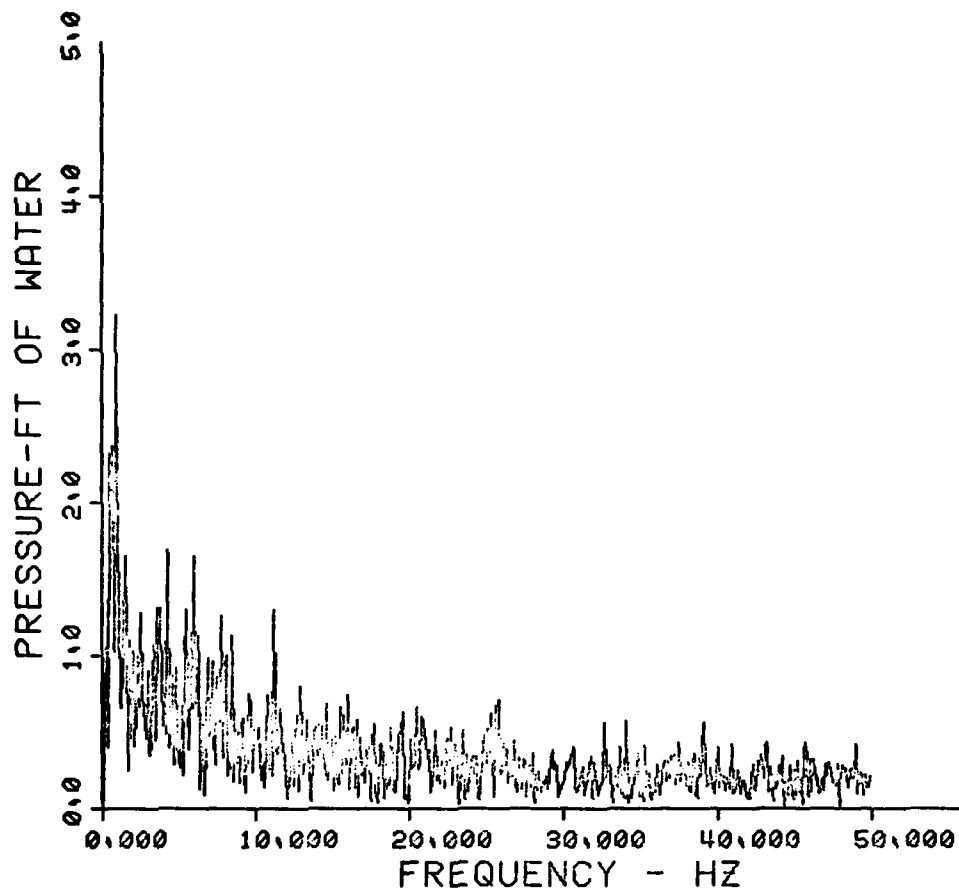
TIME - HISTORY
 FLOOD CONTROL AND IRRIGATION
 OUTLET SYSTEM
 TEST 507 TRANSDUCERS I-VIII
 INSTANTANEOUS TORQUE ON VALVE



LEGEND

MASTER VANE 12:00 O'CLOCK
 NET HEAD 561 FT OF WATER
 SLEEVE TRAVEL 32.4"

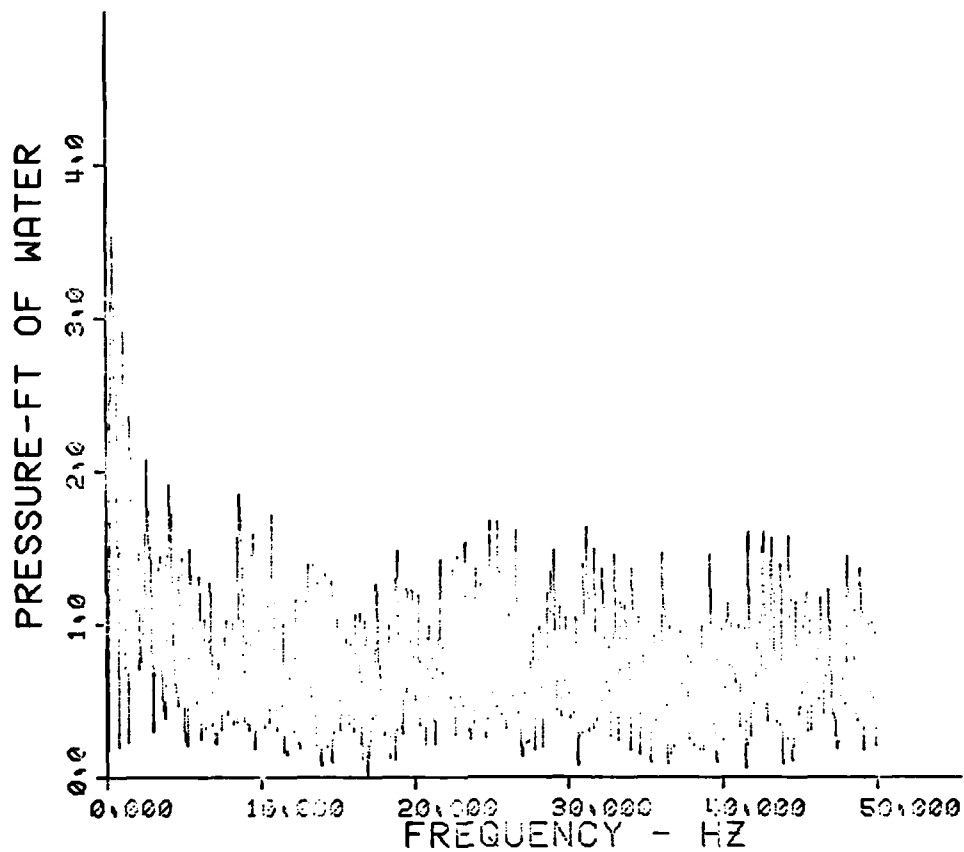
TIME - HISTORY
 FLOOD CONTROL AND IRRIGATION
 OUTLET SYSTEM
 TEST 506 TRANSDUCERS I-VIII
 INSTANTANEOUS TORQUE ON VALVE



LEGEND

MASTER VANE 12:00 O'CLOCK
NET HEAD 147 FT OF WATER
SLEEVE TRAVEL 27.7"
PREDOMINANT FREQUENCY .. 1.0 Hz

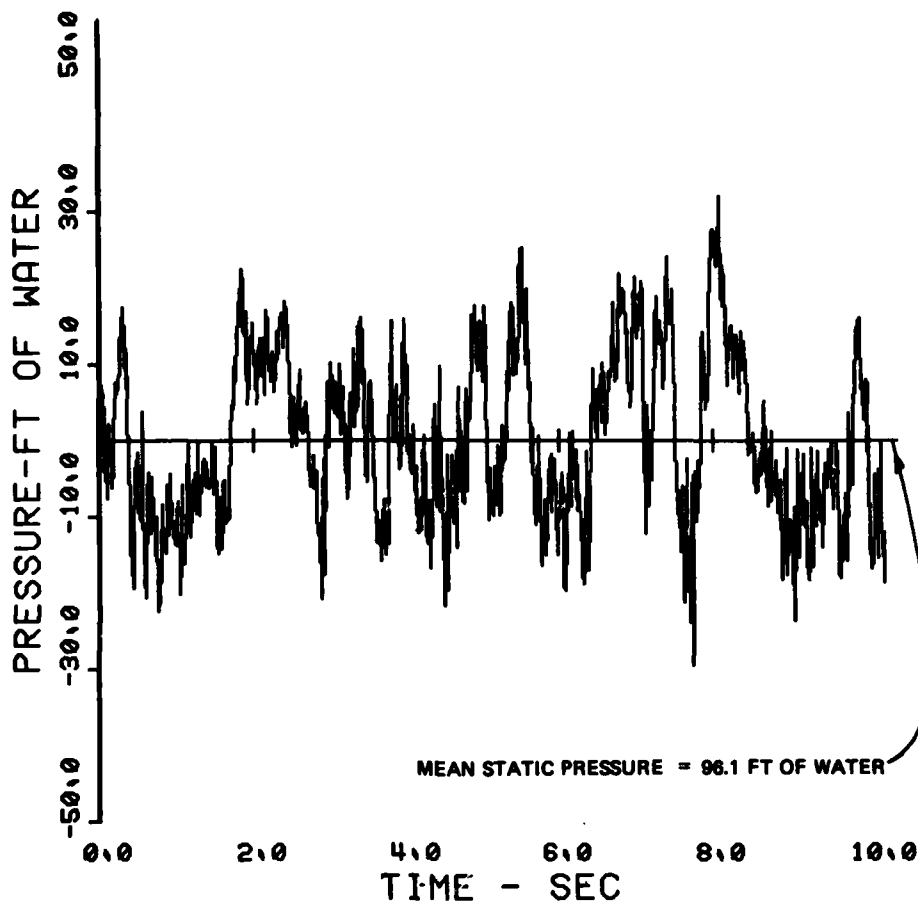
AMPLITUDE SPECTRUM
LOW-LEVEL OUTLET WORKS
TEST 134 TRANSDUCERS I-VIII
TORQUE FREQUENCY SPECTRA



LEGEND

MASTER VANE 12:00 O'CLOCK
 NET HEAD 561 FT OF WATER
 SLEEVE TRAVEL 32.4"
 PREDOMINANT FREQUENCY 0.5 HZ

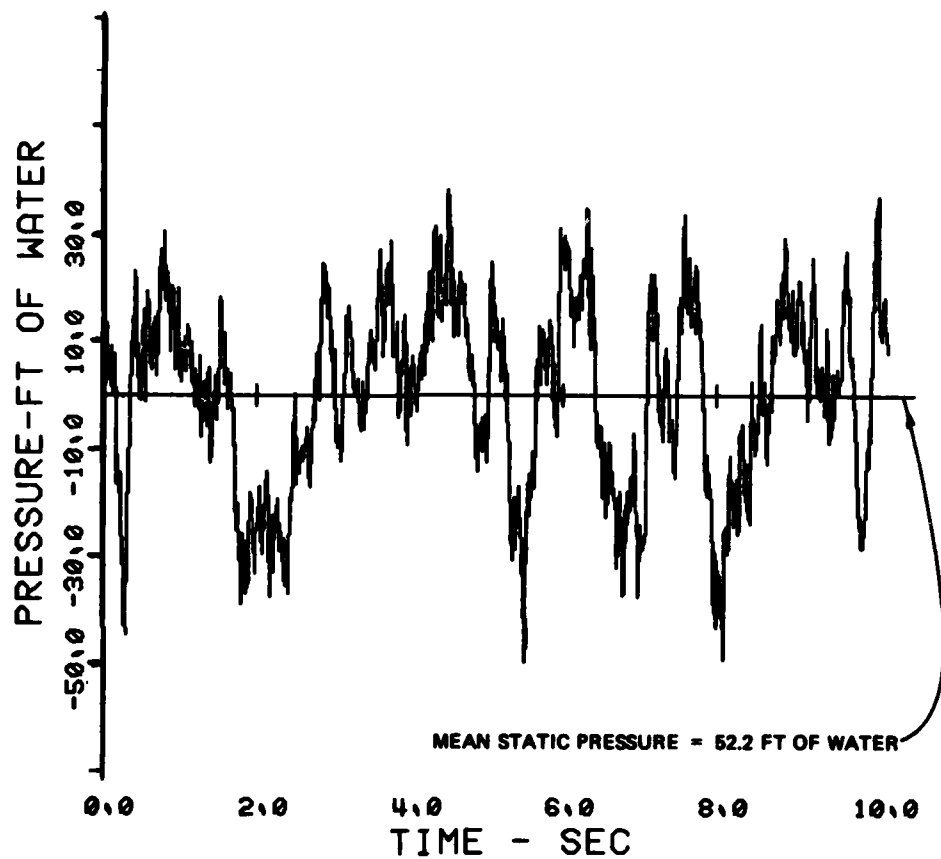
AMPLITUDE SPECTRUM
FLOOD CONTROL AND IRRIGATION
OUTLET SYSTEM
TEST 508 TRANSDUCERS I-VIII
TORQUE FREQUENCY SPECTRA



LEGEND

MASTER VANE 10:30 O'CLOCK
 NET HEAD 147 FT OF WATER
 SLEEVE TRAVEL 27.7"
 MEAN STATIC PRESSURE ... 96.1 FT OF WATER

TIME-HISTORY
 LOW-LEVEL OUTLET WORKS
 TEST 115 TRANSDUCER 1_D
 MAXIMUM LOADING CONDITION

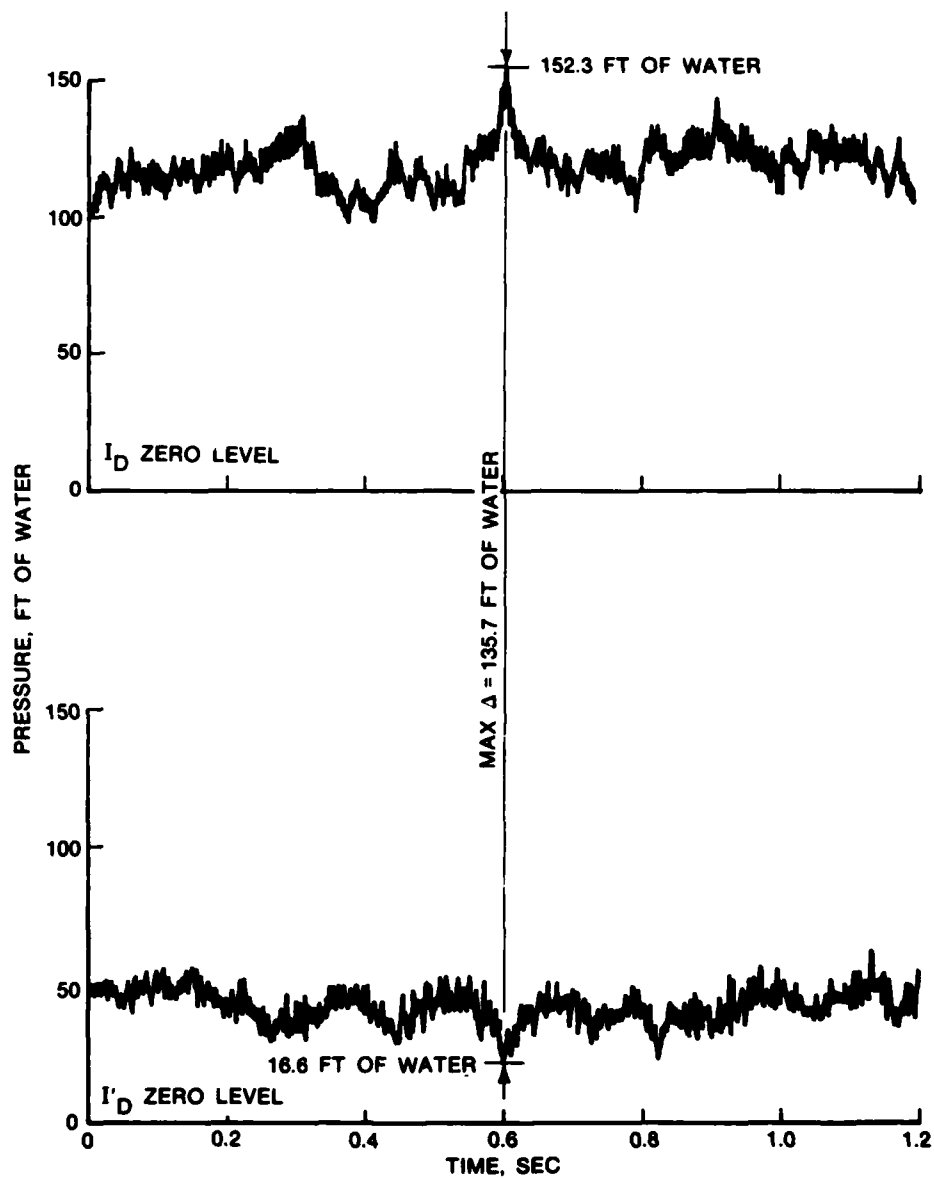


LEGEND

MASTER VANE 10:30 O'CLOCK
 NET HEAD 147 FT OF WATER
 SLEEVE TRAVEL 27.7"
 MEAN STATIC PRESSURE 52.2 FT OF WATER

TIME-HISTORY

LOW-LEVEL OUTLET WORKS
 TEST 115 TRANSDUCER I_D
 MAXIMUM LOADING CONDITION

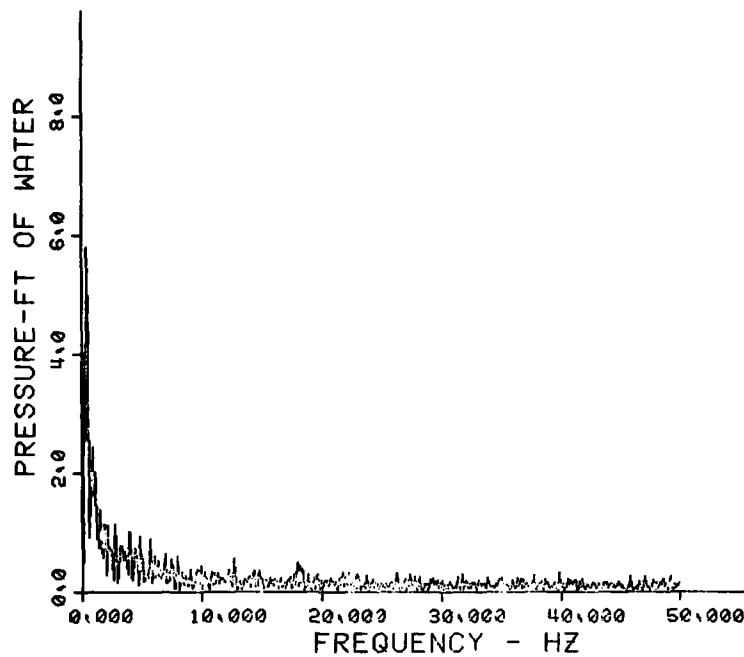


LEGEND

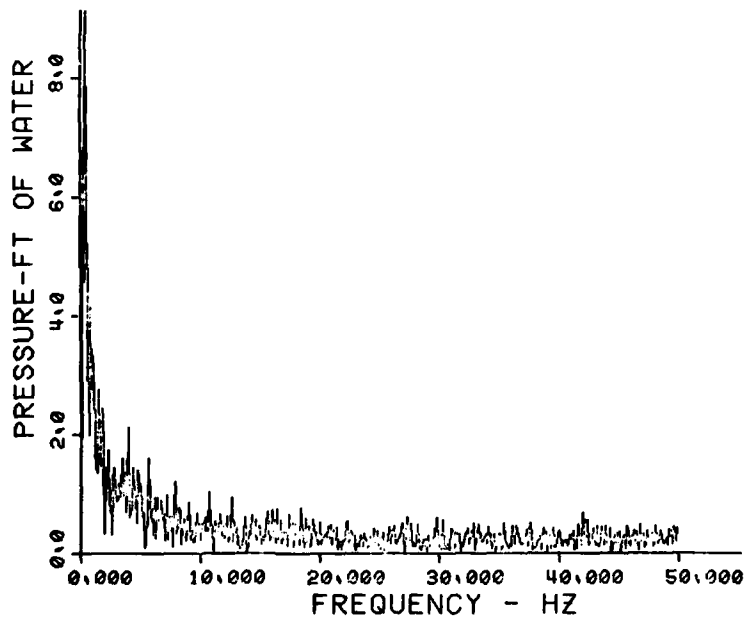
MASTER VANE 10:30 O'CLOCK
 NET HEAD 147 FT OF WATER
 SLEEVE TRAVEL 27.7"

ANALOG TRACE OF PRESSURES

LOW-LEVEL OUTLET WORKS
 TEST 115 TRANSDUCERS I_D & I'_D
 MAXIMUM LOADING CONDITION



a. TRANSDUCER I_D



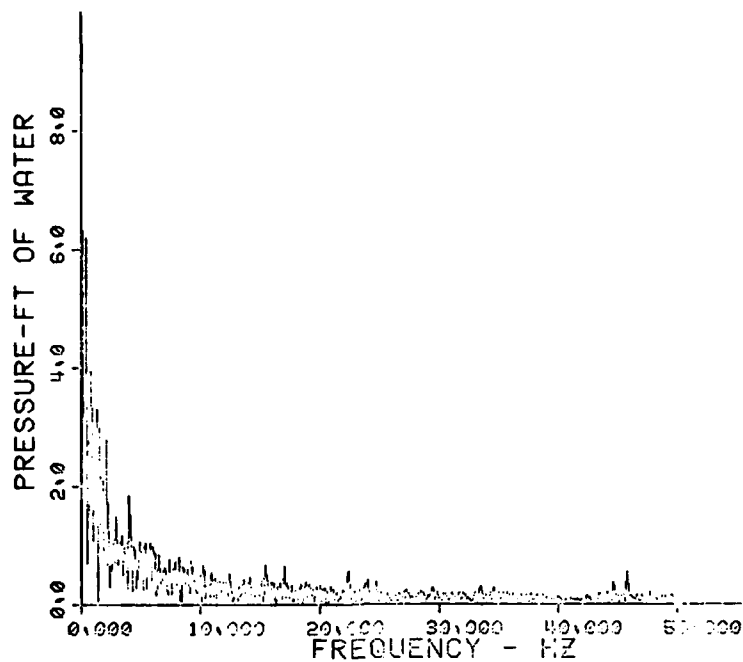
b. TRANSDUCER I_D

LEGEND

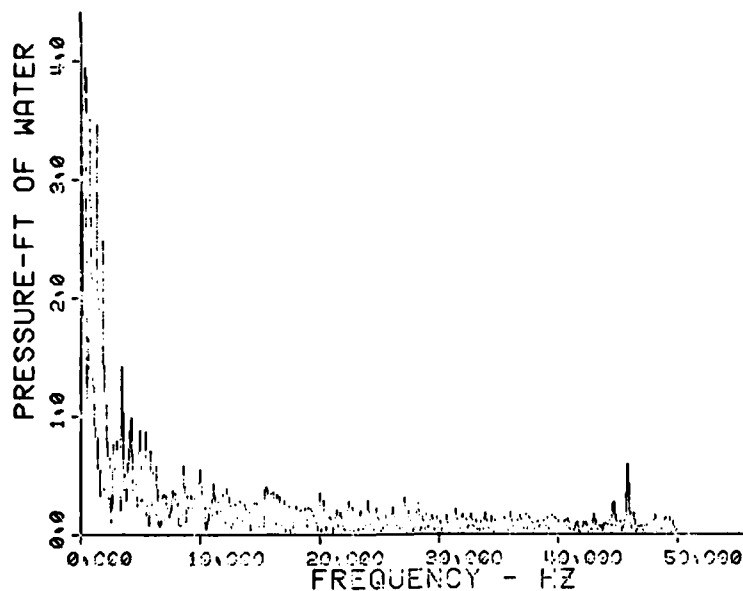
MASTER VANE 10:30 O'CLOCK
 NET HEAD 147 FT OF WATER
 SLEEVE TRAVEL 27.7 IN.
 PREDOMINANT FREQUENCY 0.5 Hz

AMPLITUDE SPECTRUM

LOW-LEVEL OUTLET WORKS
 TEST 115 TRANSDUCERS I_D AND I_D
 MAXIMUM LOADING CONDITION
 0-50 Hz



a. TRANSDUCER I_D; PREDOMINANT FREQUENCY 0.2 Hz



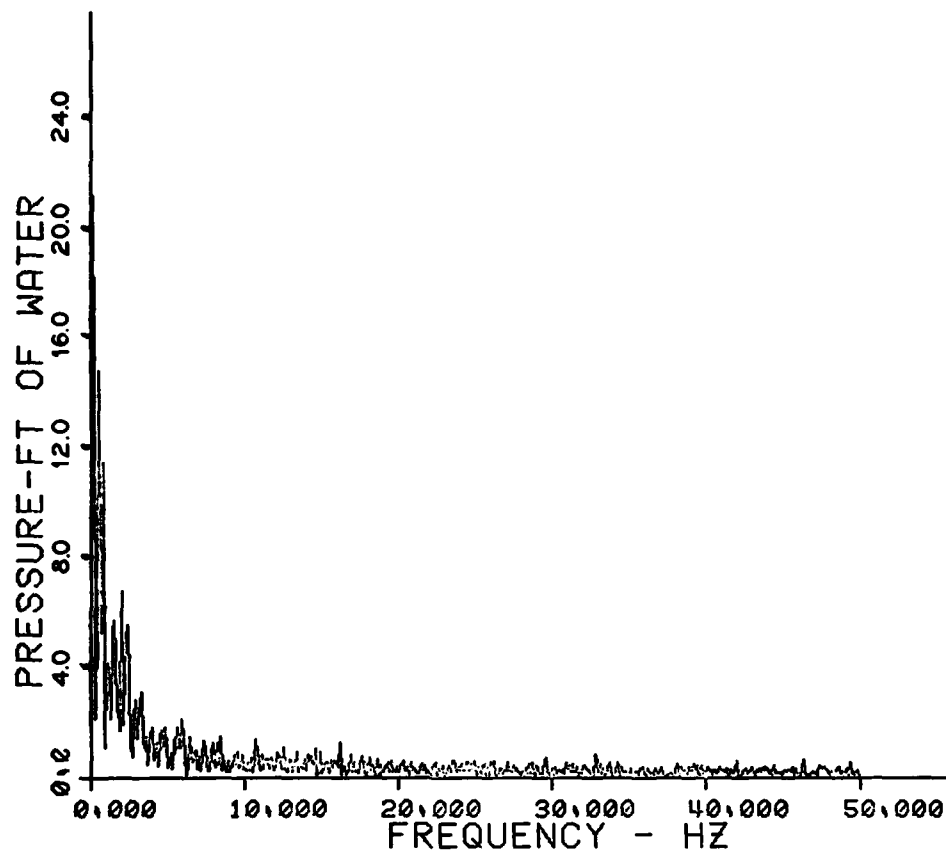
b. TRANSDUCER I_b; PREDOMINANT FREQUENCY 0.4 Hz

LEGEND

MASTER VANE 6:00 O'CLOCK
 NET HEAD 561 FT OF WATER
 SLEEVE TRAVEL 32.4 IN.

AMPLITUDE SPECTRUM

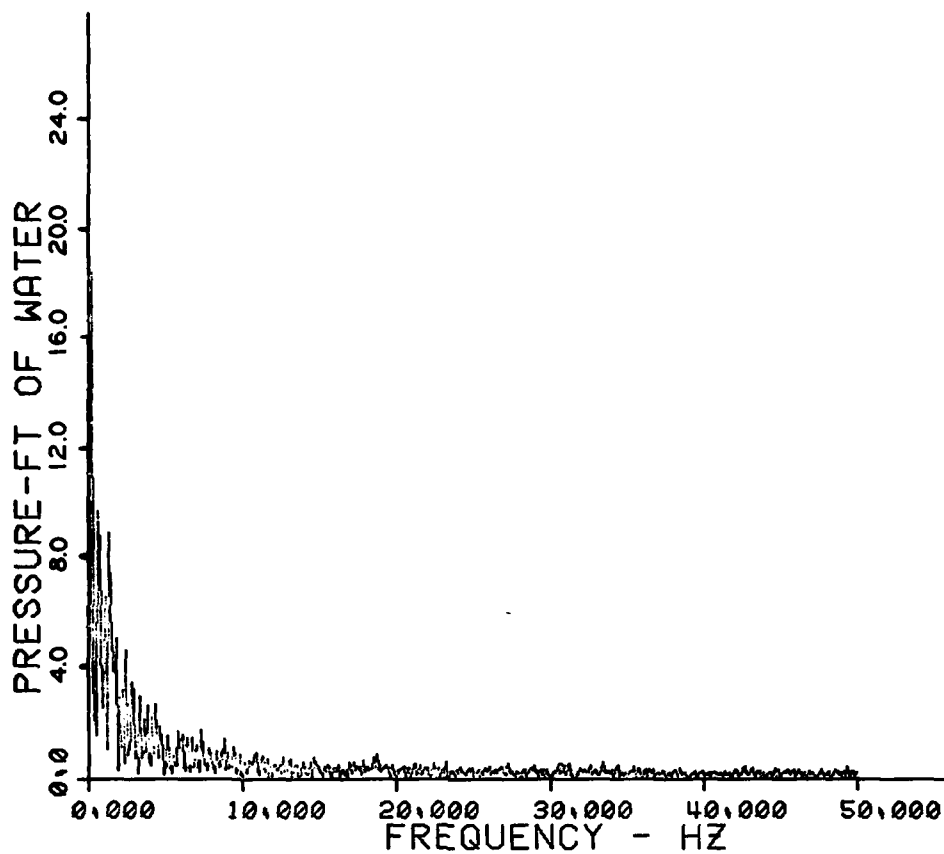
FLOOD CONTROL AND IRRIGATION
 OUTLET SYSTEM
 TEST 522 TRANSDUCERS I_D AND I_b
 MAXIMUM LOADING CONDITION
 0-50 Hz



LEGEND

MASTER VANE 10:30 O'CLOCK
 NET HEAD 147 FT OF WATER
 SLEEVE TRAVEL 27.7"
 PREDOMINANT FREQUENCY .. 0.2 Hz

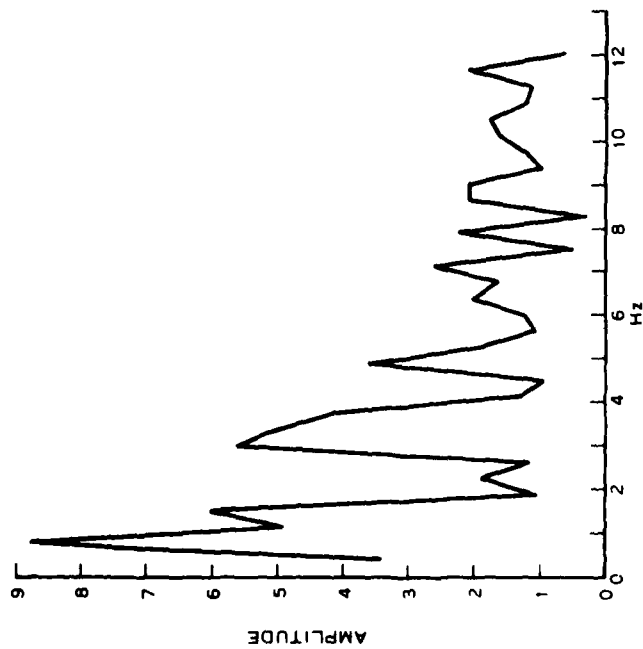
AMPLITUDE SPECTRUM
 LOW-LEVEL OUTLET WORKS
 TEST 115 TRANSDUCERS $I_D - I'_T$
 DIFFERENTIAL PRESSURE AT



LEGEND

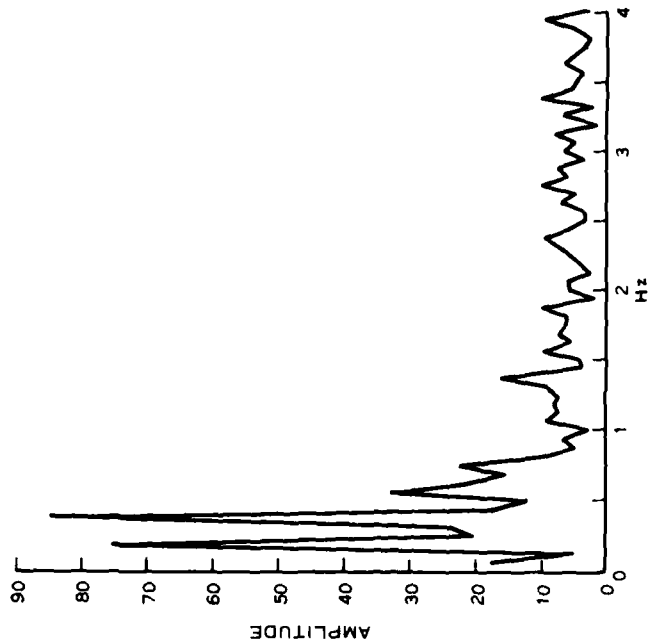
MASTER VANE 6:00 O'CLOCK
NET HEAD 561 FT OF WATER
SLEEVE TRAVEL 32.4"
PREDOMINANT FREQUENCY .. 0.3 Hz

AMPLITUDE SPECTRUM
FLOOD CONTROL AND IRRIGATION
OUTLET SYSTEM
TEST 522 TRANSDUCERS I_D - I'_D
DIFFERENTIAL PRESSURE AT D



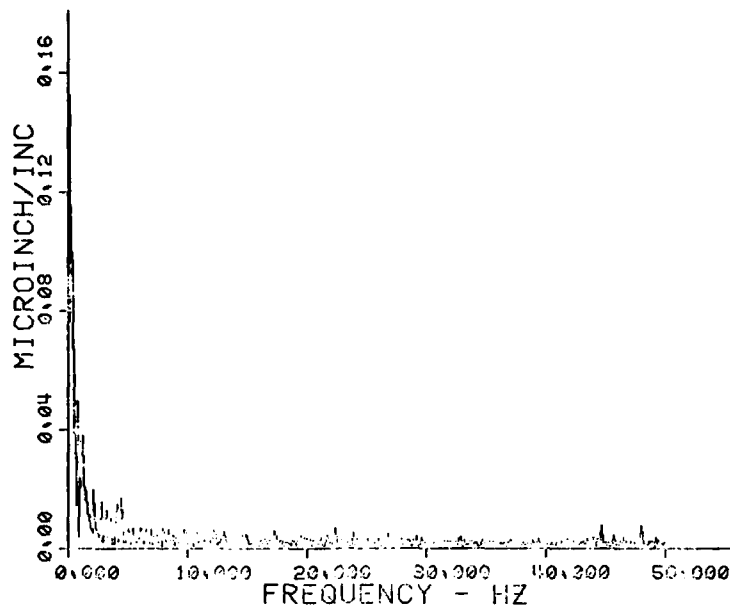
a. Small-Scale Flutter of Injected Dye

NOTE: The amplitude is a relative measure of the position of the injected dye with respect to the conduit center line

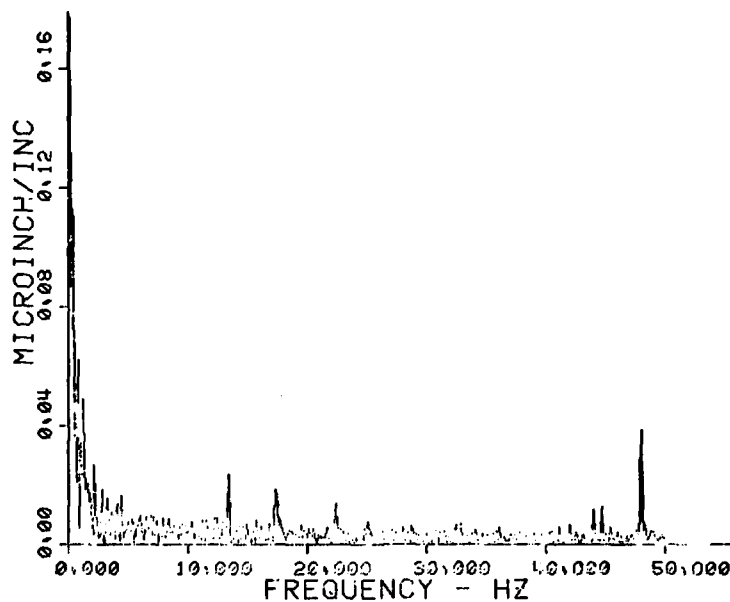


b. Large-Scale Oscillation of Injected Dye

AMPLITUDE SPECTRA OF INJECTED DYE
Low-Level Outlet Works



a. TRANSDUCER V_{sg}

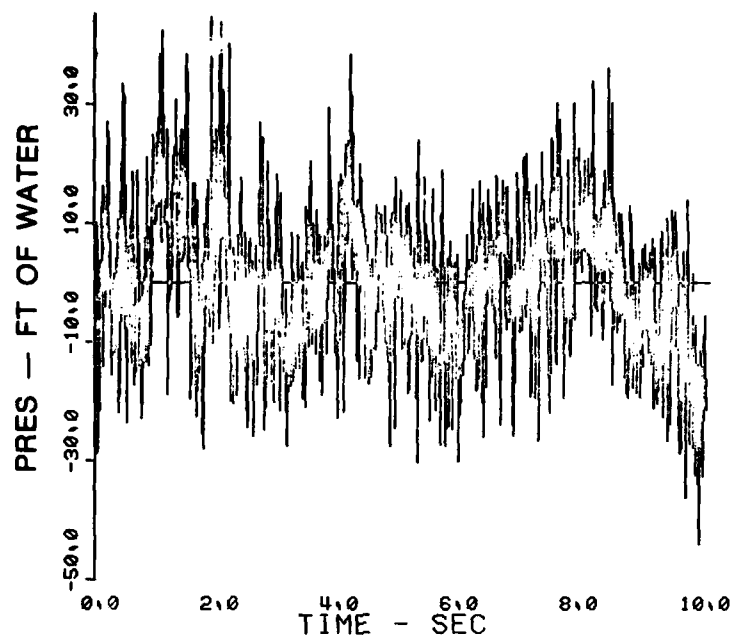


b. TRANSDUCER V'_{sg}

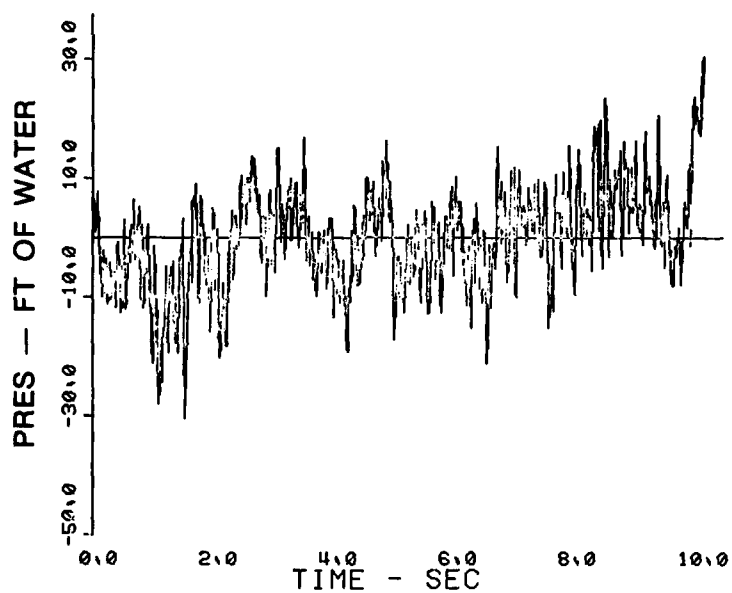
LEGEND

MASTER VANE 6:00 O'CLOCK
 NET HEAD 561 FT OF WATER
 SLEEVE TRAVEL 32.4 IN.
 PREDOMINANT FREQUENCY 0.2 Hz

AMPLITUDE SPECTRUM
 FLOOD CONTROL AND IRRIGATION
 OUTLET SYSTEM
 TEST 522 TRANSDUCERS V_{sg} AND V'_{sg}
 MAXIMUM LOADING CONDITION



a. TRANSDUCER I_D ; MEAN STATIC
PRESSURE 196.4 FT OF WATER



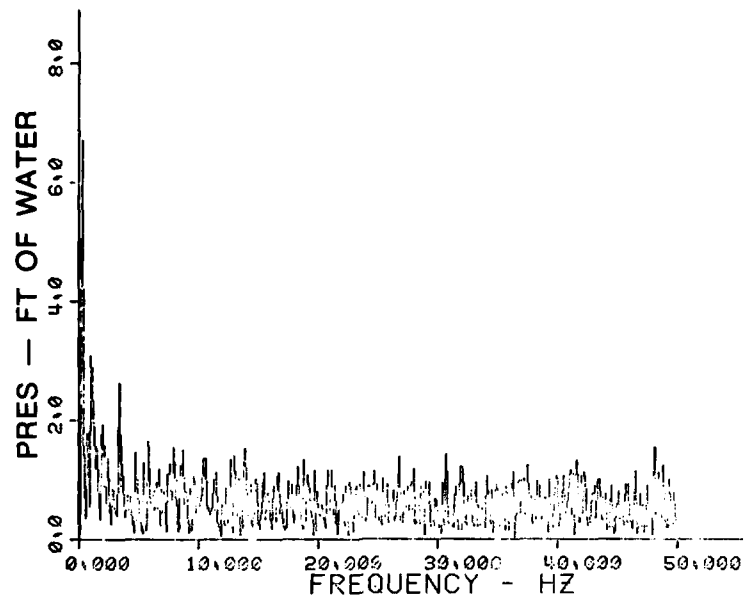
b. TRANSDUCER I_D ; MEAN STATIC
PRESSURE 172.5 FT OF WATER

LEGEND

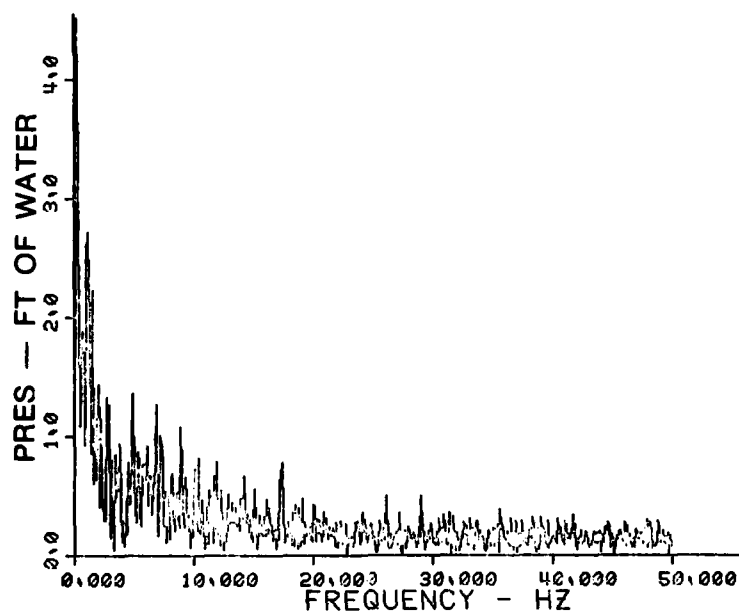
MASTER VANE 4:30 O'CLOCK
NET HEAD 561 FT OF WATER
SLEEVE TRAVEL 32.4 IN.

TIME-HISTORY

FLOOD CONTROL AND IRRIGATION
OUTLET SYSTEM
TEST 614 TRANSDUCERS I_D AND I_b
ONE-VALVE OPERATION



a. TRANSDUCER I_D ; PREDOMINANT FREQUENCY 0.4 Hz



b. TRANSDUCER I_h ; PREDOMINANT FREQUENCY 0.3 Hz

LEGEND

MASTER VANE 4:30 O'CLOCK
 NET HEAD 561 FT OF WATER
 SLEEVE TRAVEL 32.4 IN.

AMPLITUDE SPECTRUM
 FLOOD CONTROL AND IRRIGATION
 OUTLET SYSTEM
 TEST 614 TRANSDUCERS I_D AND I_h
 ONE-VALVE OPERATION

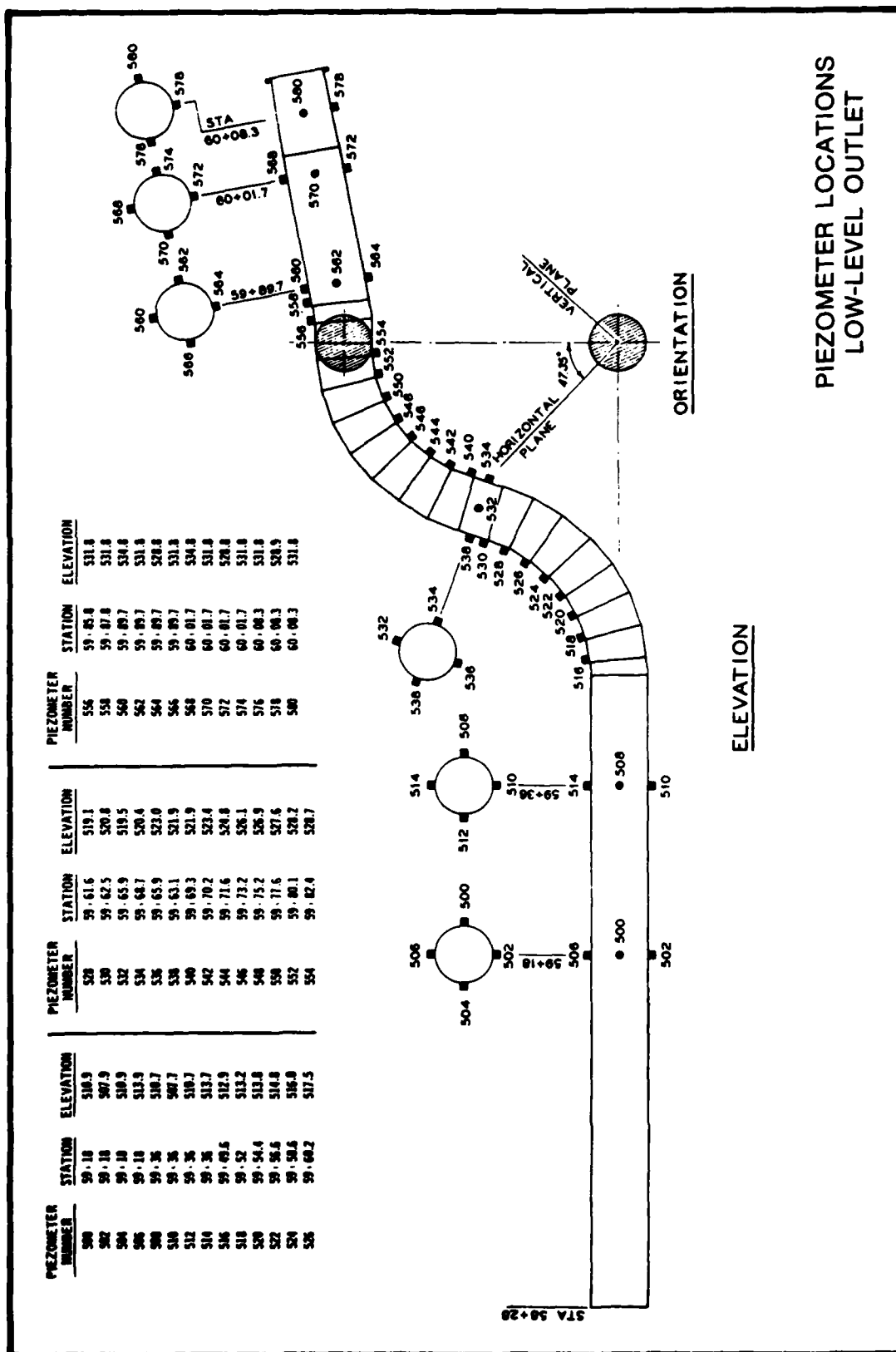
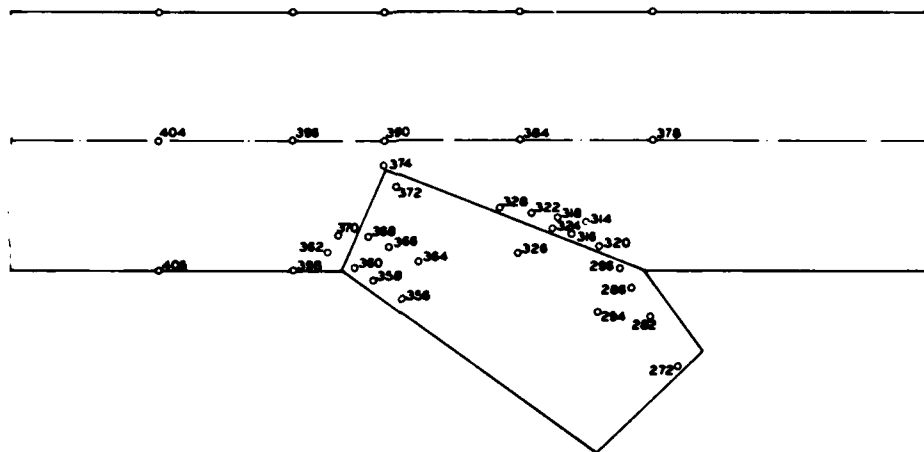
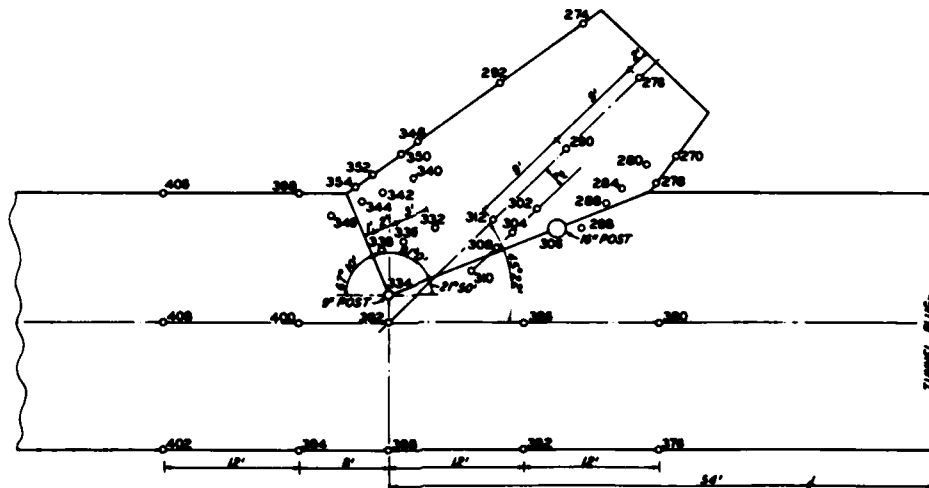


PLATE 30

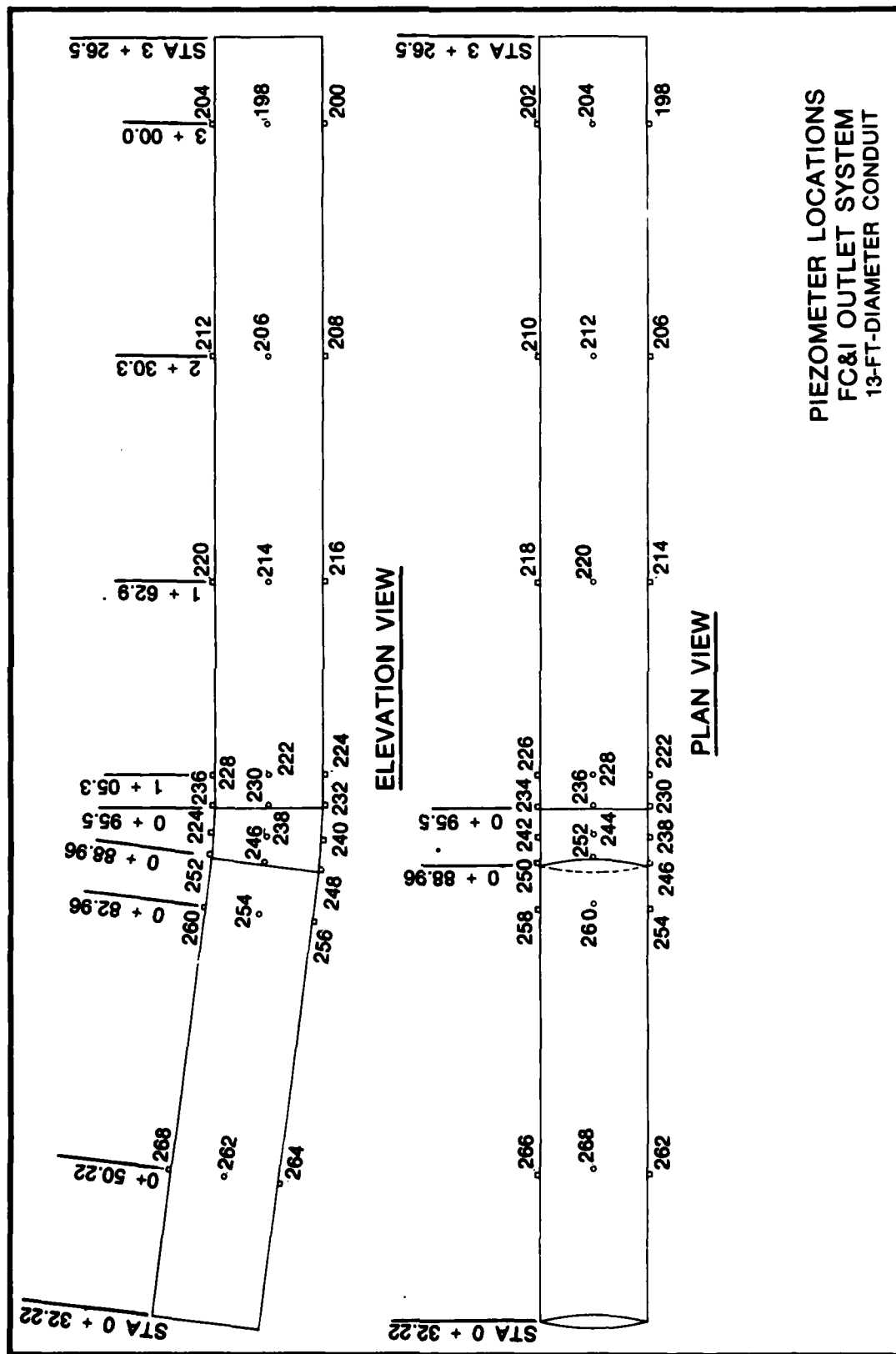


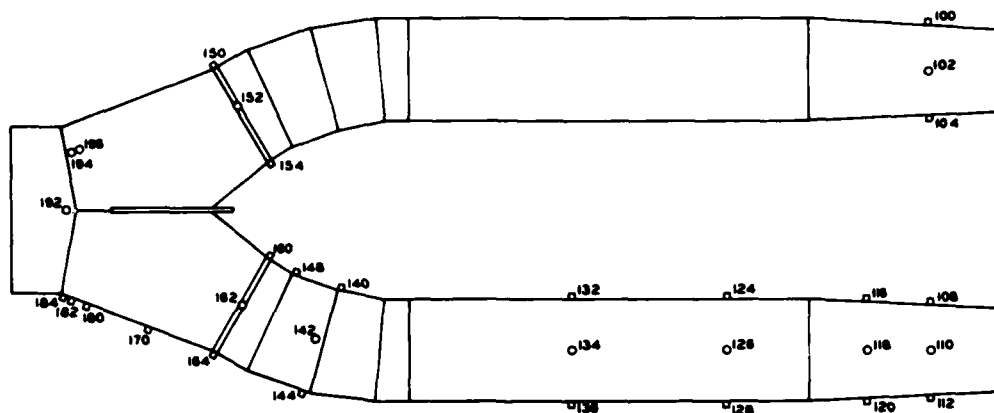
BOTTOM



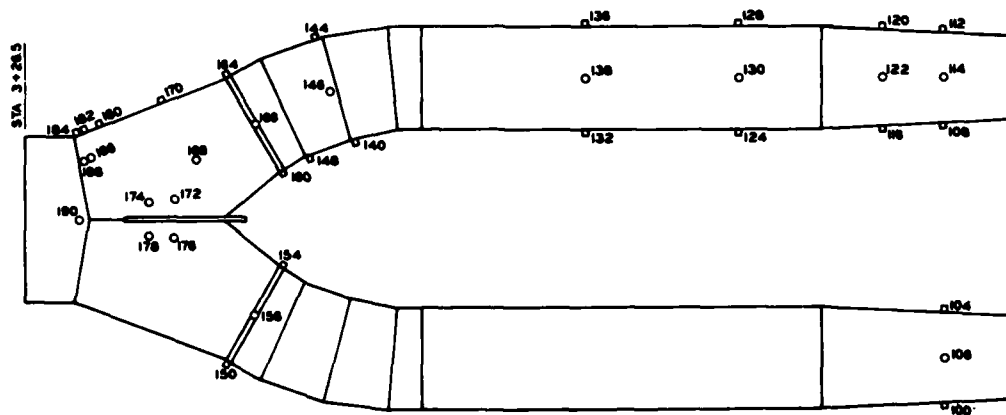
TOP

PIEZOMETER LOCATIONS
MAIN TUNNEL AND FC&I
BIFURCATION DETAILS



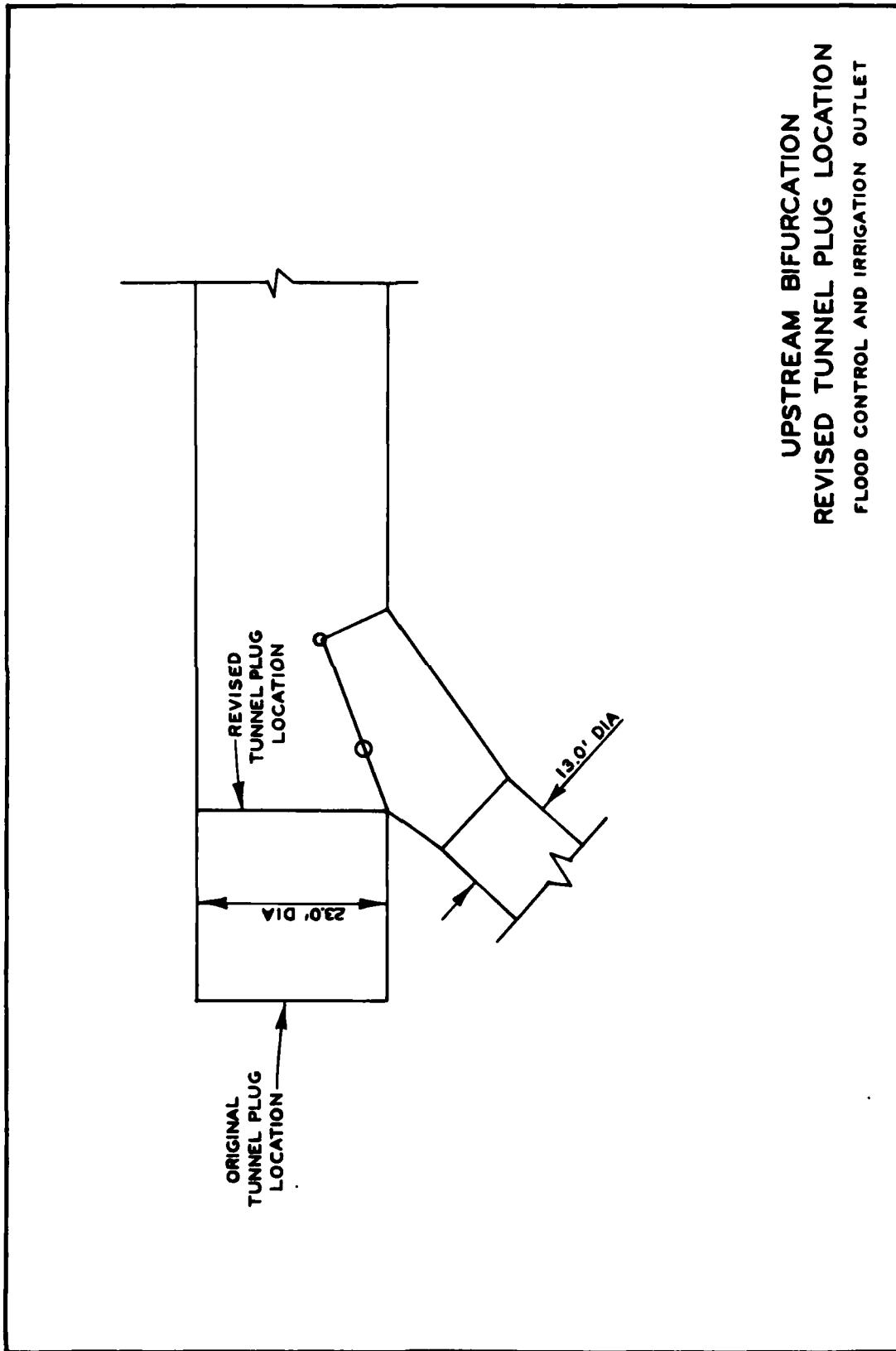


BOTTOM VIEW



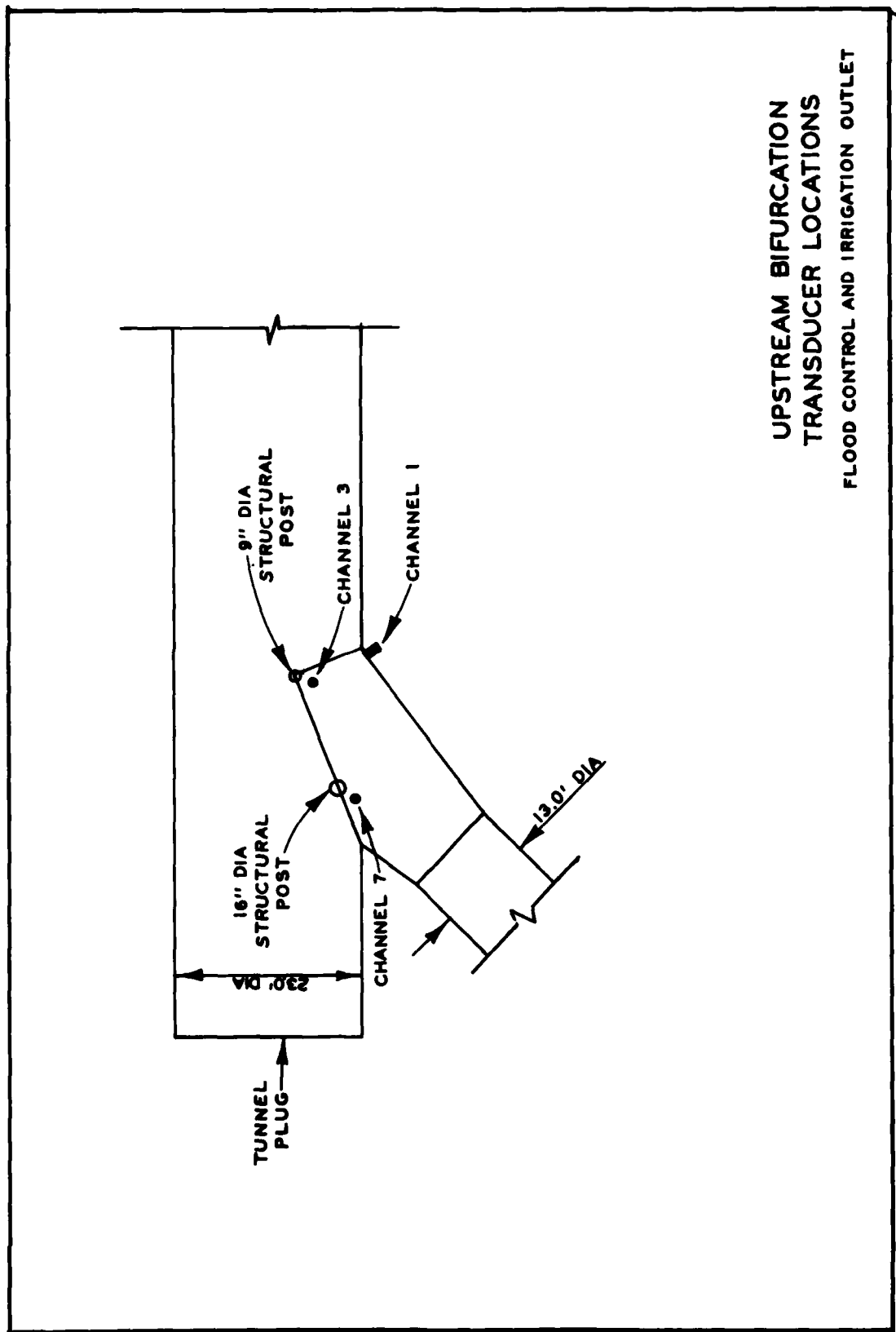
TOP VIEW

**PIEZOMETER LOCATIONS
FC&I OUTLET SYSTEM
DOWNSTREAM BIFURCATION**

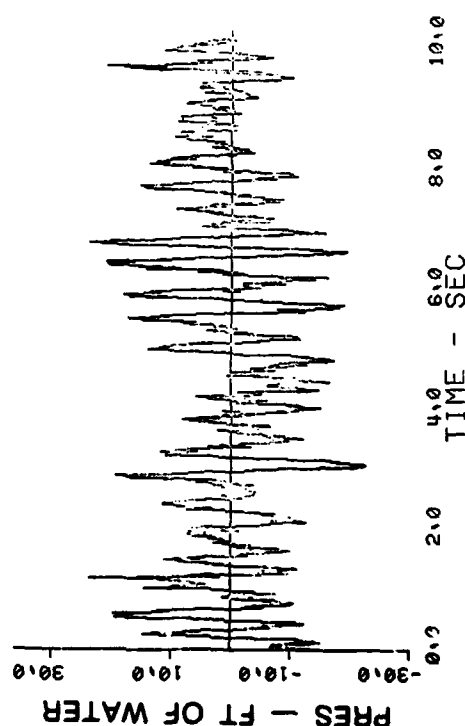
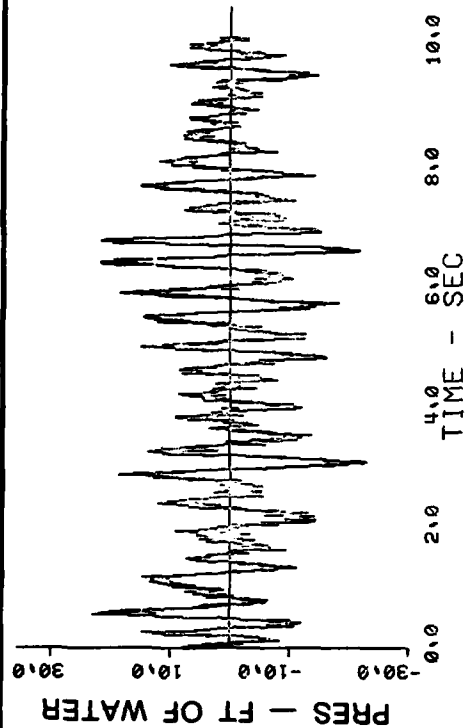
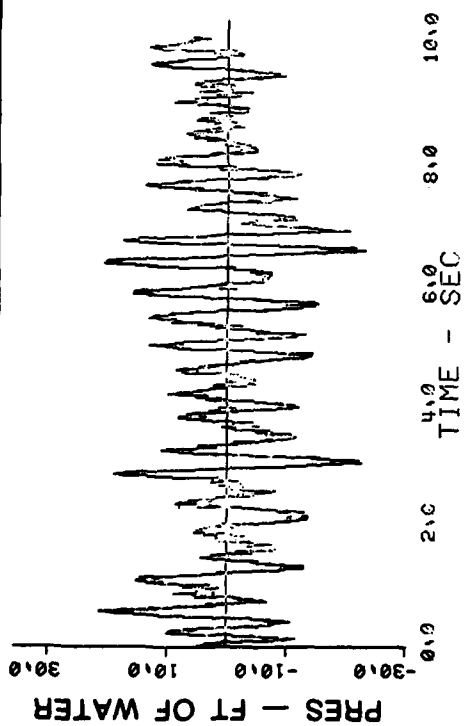


UPSTREAM BIFURCATION
REVISED TUNNEL PLUG LOCATION
FLOOD CONTROL AND IRRIGATION OUTLET

PLATE 34



UPSTREAM BIFURCATION
TRANSDUCER LOCATIONS
FLOOD CONTROL AND IRRIGATION OUTLET

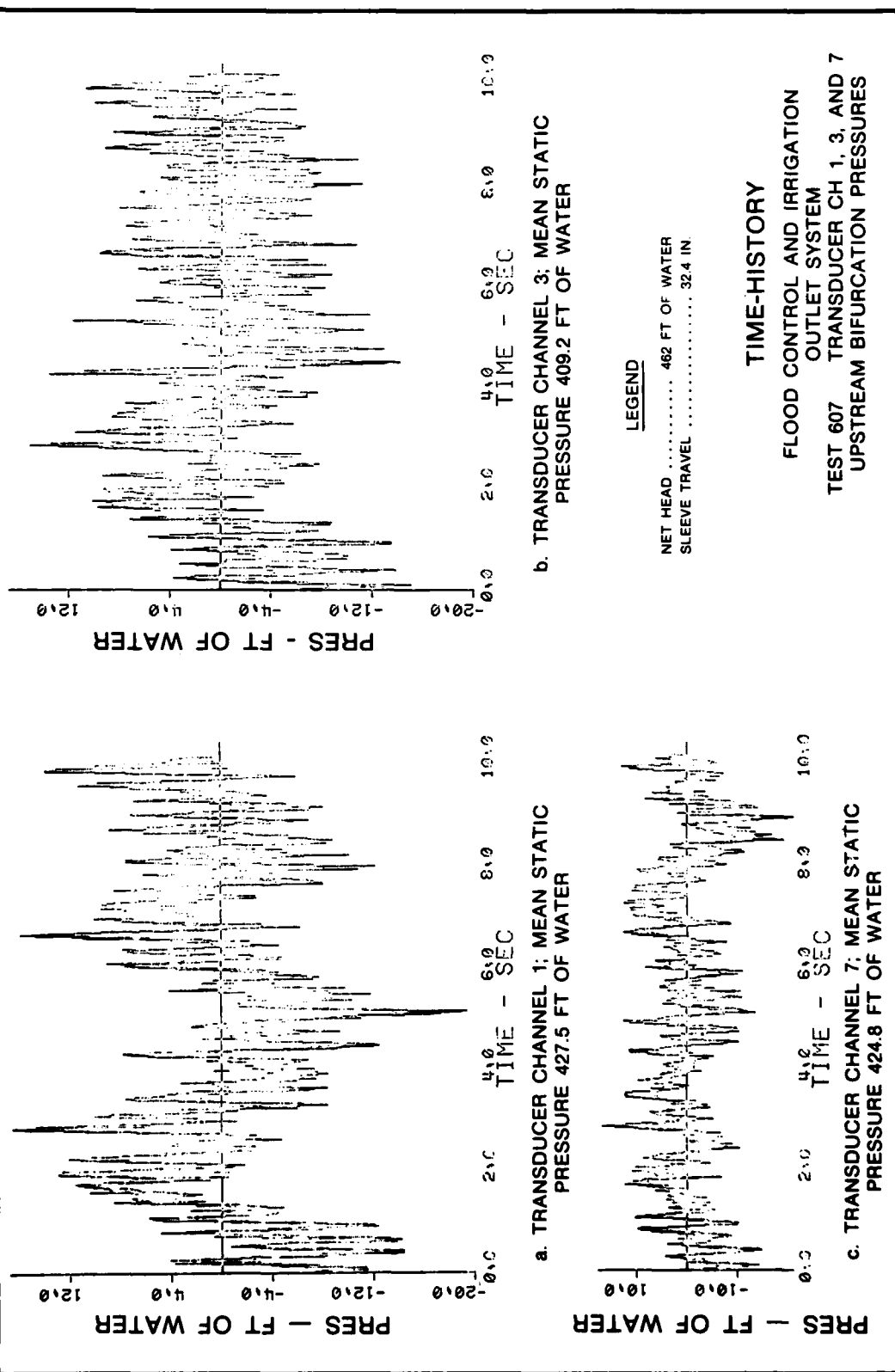


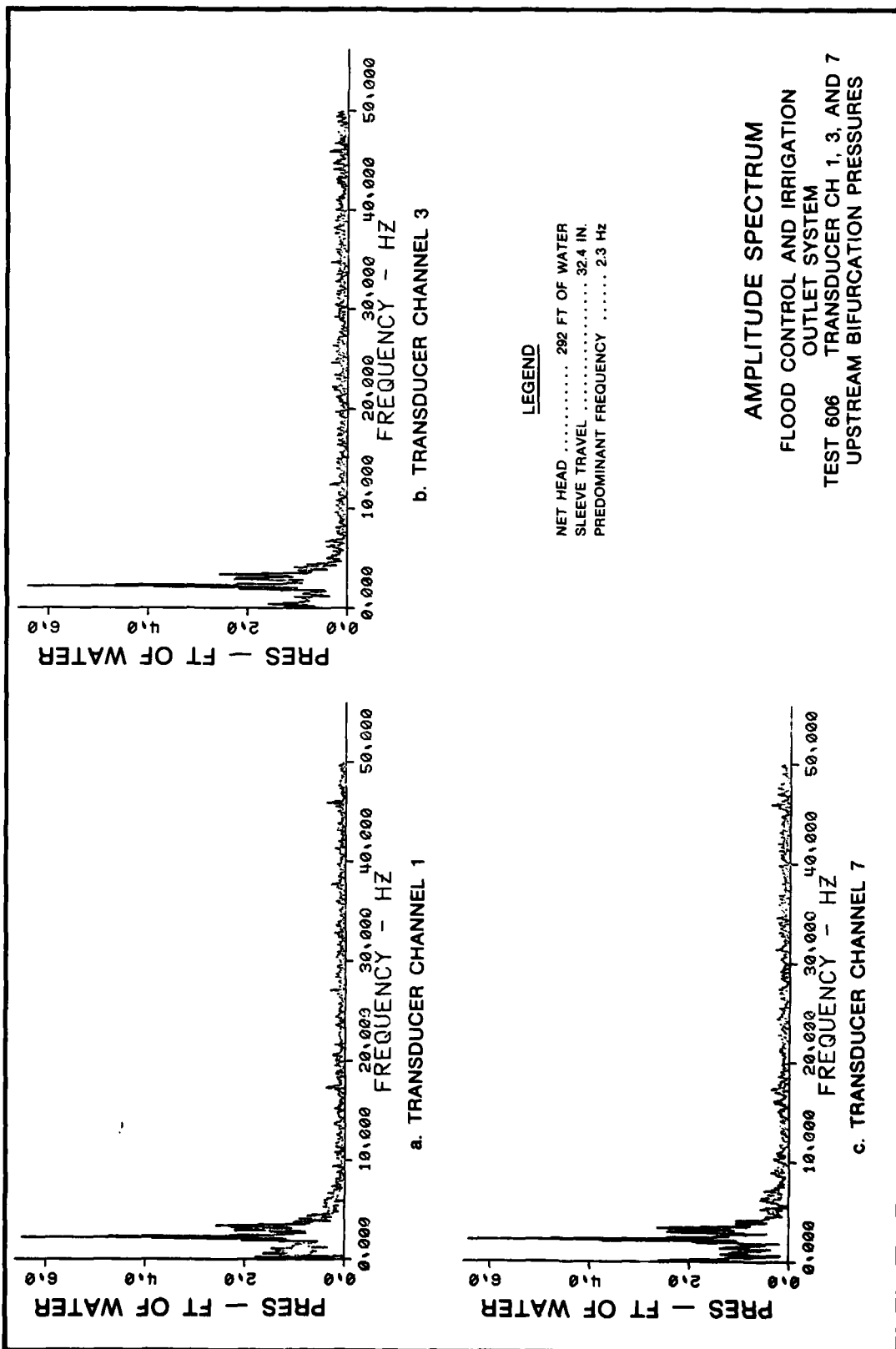
LEGEND

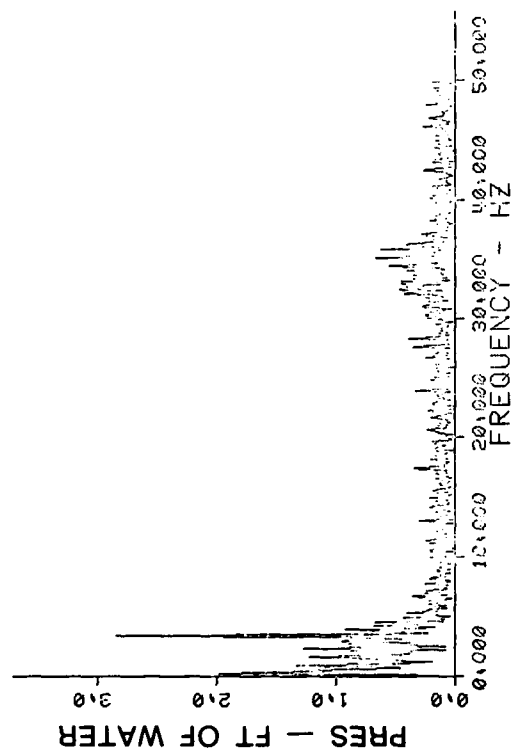
NET HEAD 292 FT OF WATER
SLEEVE TRAVEL 32.4 IN.

TIME-HISTORY

FLOOD CONTROL AND IRRIGATION
OUTLET SYSTEM
TEST 606 TRANSDUCER CH 1, 3, AND 7
UPSTREAM BIFURCATION PRESSURES





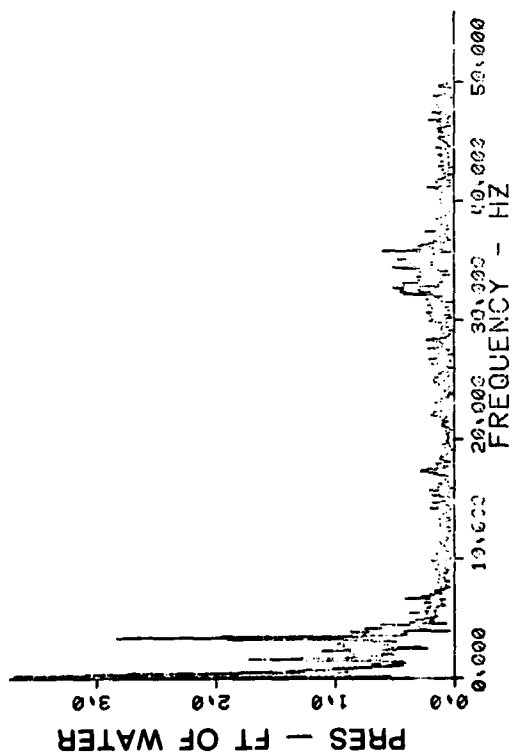


b. TRANSDUCER CHANNEL 3;
PREDOMINANT FREQUENCY 3.5 Hz

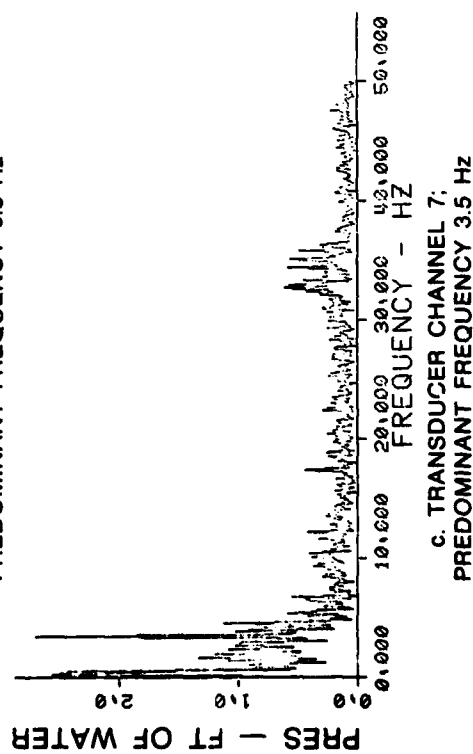
LEGEND

NET HEAD 462 FT OF WATER
SLEEVE TRAVEL 32.4 IN.

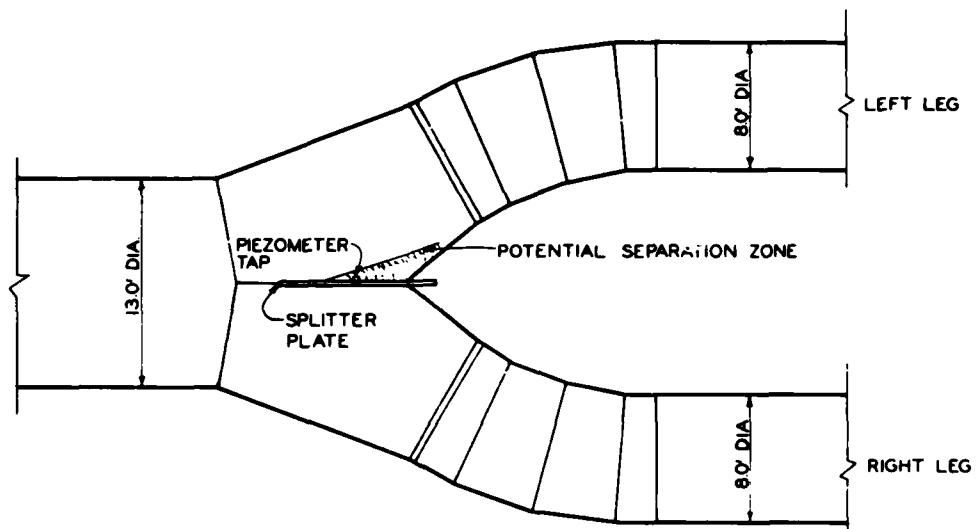
AMPLITUDE SPECTRUM
FLOOD CONTROL AND IRRIGATION
OUTLET SYSTEM
TEST 607 TRANSDUCER CH 1, 3, AND 7
UPSTREAM BIFURCATION PRESSURES



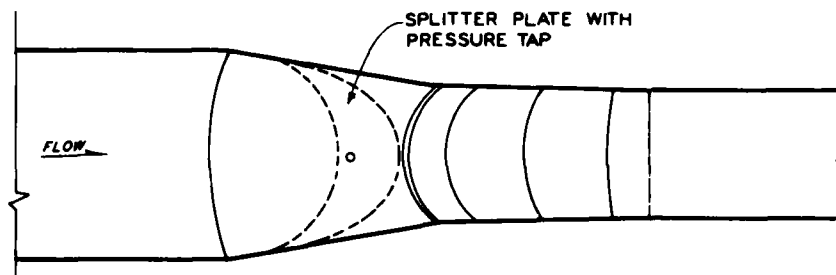
a. TRANSDUCER CHANNEL 1;
PREDOMINANT FREQUENCY 0.3 Hz



c. TRANSDUCER CHANNEL 7;
PREDOMINANT FREQUENCY 3.5 Hz



PLAN VIEW



ELEVATION VIEW

DOWNSTREAM BIFURCATION
LOCATION OF PIEZOMETER
ON SPLITTER PLATE
FC&I OUTLET SYSTEM

AD-A099 595

ARMY ENGINEER WATERWAYS EXPERIMENT STATION VICKSBURG--ETC F/G 13/11
FIXED-CONE VALVES, NEW MELONES DAM, CALIFORNIA. HYDRAULIC MODEL--ETC(U)
APR 81 S T MAYNORD, J L GRACE

UNCLASSIFIED

WES/TR/HL-81-4

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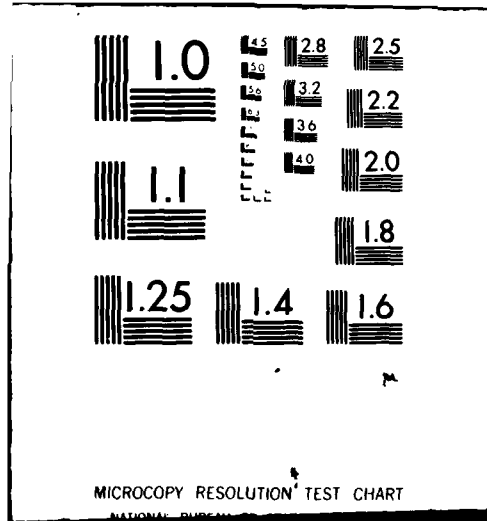
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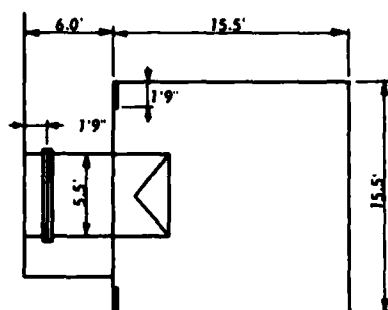
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FILED

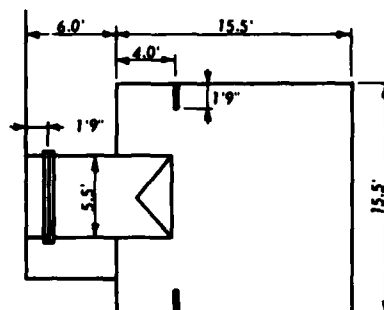
7-81

DTIC

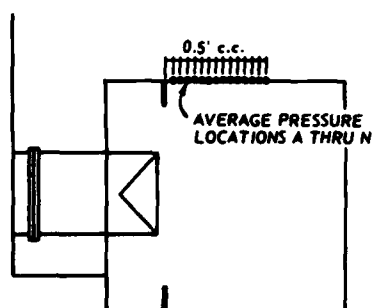




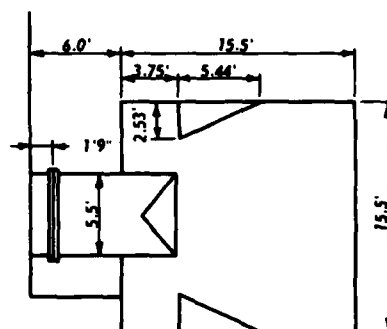
a ORIGINAL 1'9" BACKSPASH PLATE



b REVISED BACKSPASH PLATE LOCATION



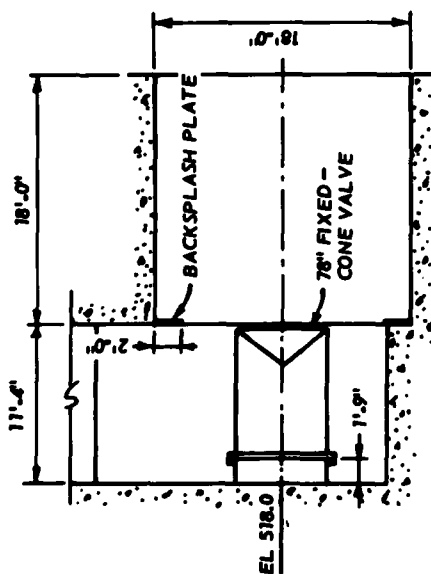
c REVISED BACKSPASH PLATE GAGE LOCATION



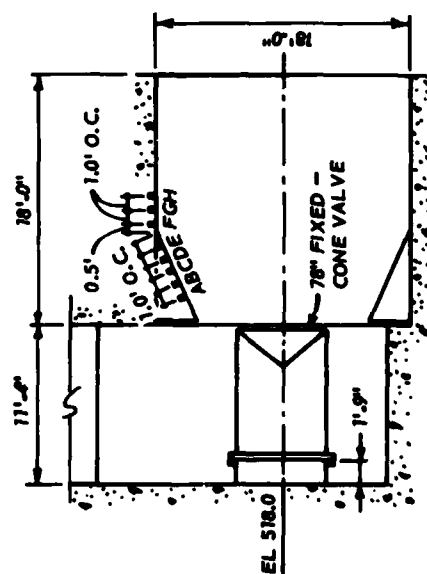
d SEGMENTED CONE DESIGN

SLEEVE TRAVEL IN.	Q CFS	NET HEAD FT	AVERAGE PRESSURE AT LOCATIONS (FT OF WATER)													
			A	B	C	D	E	F	G	H	I	J	K	L	M	N
27.7	1730	147	0	0	0	0	0	0	5	11	47	48	14	12	8	10
20.2	1980	219	0	0	0	0	0	2	5	18	61	96	4	10	5	9
14.2	1340	311	0	0	0	0	0	2	4	20	90	98	-5	8	4	8
9.7	1090	419	0	0	0	0	0	2	2	14	108	48	-10	4	2	4
8.2	870	539	0	0	0	0	0	0	0	4	96	28	-2	0	0	0

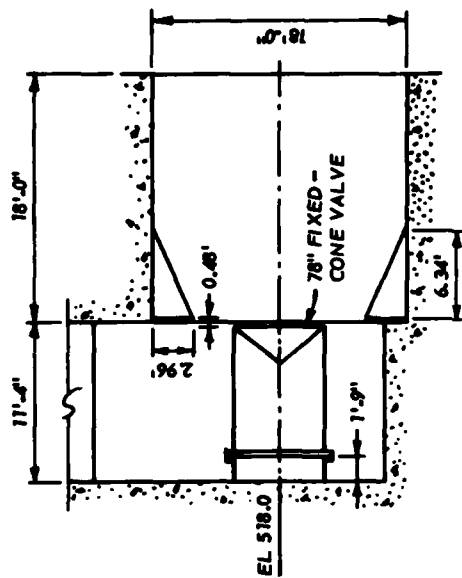
LOW-LEVEL OUTLET WORKS HOOD DESIGN



ORIGINAL DESIGN



PIEZOMETER LOCATIONS



SEGMENTED CONE DESIGN

SLEEVE TRAVEL IN.	Q CFS	NET HEAD FT	AVERAGE PRESSURE AT LOCATIONS (FT OF WATER)							
			A	B	C	D	E	F	G	H
31.2	9710	561	0.0	0.0	48.0	19.0	2.0	86.0	26.0	6.0
23.6	7310	581	0.0	0.0	10.0	48.0	1.0	96.0	18.0	8.0
16.6	5310	592	0.0	0.0	1.0	104.0	-14.0	104.0	6.0	6.0
11.3	3450	599	0.0	0.0	0.0	72.0	-16.0	70.0	7.0	5.0

HOOD DETAILS
FLOOD CONTROL AND IRRIGATION
OUTLET SYSTEM

APPENDIX A: TEST RESULTS AT HEADS LESS THAN DESIGN HEAD

1. The following tabulation shows the additional model tests that were conducted and the corresponding plate number of test results. Each plate (Plates A1-A20) shows the time-history of differential pressure acting at location D and the amplitude spectrum of this time-history.

<u>Test No.</u>	<u>Sleeve Travel in. (%)</u>	<u>Net Head ft</u>	<u>Pool El ft msl</u>	<u>Plate No.</u>
<u>FC&I Valve</u>				
721	11.3 (25)	288	808	A1
720	16.6 (40)	285	808	A2
719	23.6 (60)	277	808	A3
718	32.4 (85)	270	808	A4
713	11.3 (25)	430	950	A5
712	16.6 (40)	423	950	A6
723	23.6 (60)	415	950	A7
722	32.4 (85)	400	950	A8
717	11.3 (25)	525	1048	A9
716	16.6 (40)	519	1048	A10
715	23.6 (60)	510	1048	A11
714	32.4 (85)	488	1048	A12
<u>Low-Level Valve</u>				
433	9.7 (25)	108	750.5	A13
431	14.2 (40)	96	750.5	A14
429	20.2 (60)	79	750.5	A15
427	27.7 (85)	54	750.5	A16
434	9.7 (25)	206	805.5	A17
432	14.2 (40)	161	805.5	A18
430	20.2 (60)	123	805.5	A19
428	27.7 (85)	89	805.5	A20

2. Minimum, average, and maximum pressures and the predominant frequency for transducers I_B , I'_B , $I_B - I'_B$, I_D , and I'_D are shown in Tables A1 and A2 for the FC&I and the low-level outlet works valves, respectively. Positive values of differential pressures at locations $I_B - I'_B$ and $I_D - I'_D$ indicate a net clockwise torque acting on the valve when looking downstream.

Table A1
FC&I - Additional Test Data

Test No.	Sleeve Travel in.	Net Head ft	Pool El ft masl	Transducer	Pressure, Feet of Water			Predominant Frequency Hz
					Minimum	Average	Maximum	
721	11.3	288	808	I _B	175	188	195	0.2
721	11.3	288	808	I' _B	182	196	203	0.2
721	11.3	288	808	I _B - I' _B	-12	-8	-4	*
721	11.3	288	808	I _D	191	205	212	0.2
721	11.3	288	808	I' _D	185	199	206	0.2
720	16.6	285	808	I _B	155	160	167	0.2
720	16.6	285	808	I' _B	166	169	176	0.2
720	16.6	285	808	I _B - I' _B	-13	-9	-4	0.2
720	16.6	285	808	I _D	178	184	192	0.2
720	16.6	285	808	I' _D	166	176	185	0.2
719	23.6	277	808	I _B	86	96	103	0.2
719	23.6	277	808	I' _B	95	102	108	0.2
719	23.6	277	808	I _B - I' _B	-16	-6	0	0.6
719	23.6	277	808	I _D	117	127	135	0.2
719	23.6	277	808	I' _D	106	117	129	0.2
718	32.4	270	808	I _B	16	25	34	0.2
718	32.4	270	808	I' _B	21	26	30	0.3
718	32.4	270	808	I _B - I' _B	-10	-1	9	0.2
718	32.4	270	808	I _D	51	60	69	0.3
718	32.4	270	808	I' _D	34	47	60	0.4
713	11.3	430	950	I _B	294	310	318	0.2
713	11.3	430	950	I' _B	289	304	313	0.2
713	11.3	430	950	I _B - I' _B	0	6	12	0.2
713	11.3	430	950	I _D	313	329	339	0.2
713	11.3	430	950	I' _D	310	326	335	0.2
712	16.6	423	950	I _B	257	271	283	0.2
712	16.6	423	950	I' _B	252	262	272	0.2
712	16.6	423	950	I _B - I' _B	1	9	17	*
712	16.6	423	950	I _D	286	298	311	0.2
712	16.6	423	950	I' _D	278	291	307	0.2
723	23.6	415	950	I _B	163	177	199	0.4
723	23.6	415	950	I' _B	173	179	185	0.3

(Continued)

* Very little pressure at all frequencies.

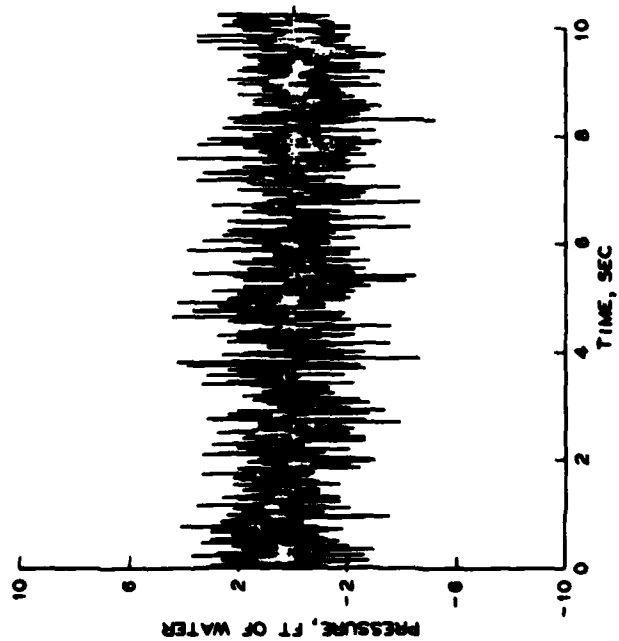
Table A1 (Concluded)

Test No.	Sleeve Travel in.	Net Head ft	Pool El ft msl	Transducer	Pressure, Feet of Water			Predominant Frequency Hz
					Minimum	Average	Maximum	
723	23.6	415	950	$I_B - I'_B$	-13	-2	18	1.9
723	23.6	415	950	I_D	214	226	241	0.4
723	23.6	415	950	I'_D	173	192	210	0.5
722	32.4	400	950	I_B	26	48	72	0.3
722	32.4	400	950	I'_B	26	32	42	0.5
722	32.4	400	950	$I_B - I'_B$	-6	16	37	*
722	32.4	400	950	I_D	90	109	130	0.3
722	32.4	400	950	I'_D	25	64	115	0.3
717	11.3	525	1048	I_B	370	380	390	0.2
717	11.3	525	1048	I'_B	374	384	393	0.4
717	11.3	525	1048	$I_B - I'_B$	-11	-4	2	0.2
717	11.3	525	1048	I_D	389	402	413	0.2
717	11.3	525	1048	I'_D	382	397	405	0.3
716	16.6	519	1048	I_B	332	341	349	0.3
716	16.6	519	1048	I'_B	337	345	351	0.4
716	16.6	519	1048	$I_B - I'_B$	-14	-4	5	0.9
716	16.6	519	1048	I_D	369	377	389	0.3
716	16.6	519	1048	I'_D	349	363	376	0.2
715	23.6	510	1048	I_B	216	236	259	0.4
715	23.6	510	1048	I'_B	215	222	233	0.6
715	23.6	510	1048	$I_B - I'_B$	-6	15	37	0.4
715	23.6	510	1048	I_D	274	289	311	0.4
715	23.6	510	1048	I'_D	228	254	287	0.4
714	32.4	488	1048	I_B	44	73	112	0.7
714	32.4	488	1048	I'_B	34	42	51	0.5
714	32.4	488	1048	$I_B - I'_B$	2	31	64	3.9
714	32.4	488	1048	I_D	136	157	187	0.4
714	32.4	488	1048	I'_D	45	93	133	0.4

Table A2
Low-Level Outlet - Additional Test Data

Test No.	Sleeve Travel in.	Net Head ft	Pool El ft msl	Transducer	Pressure, Feet of Water			Predominant Frequency Hz
					Minimum	Average	Maximum	
433	9.7	108	750.5	I _B	84.4	88.8	93.5	3.5
433	9.7	108	750.5	I' _B	90.1	95.0	99.2	3.5
433	9.7	108	750.5	I _B - I' _B	-8.4	-6.1	-3.7	*
433	9.7	108	750.5	I _D	88.6	95.6	101.3	3.5
433	9.7	108	750.5	I' _D	76.2	83.4	89.4	3.5
431	14.2	96	750.5	I _B	68.3	71.5	75.6	0.2
431	14.2	96	750.5	I' _B	63.6	67.4	71.7	0.3
431	14.2	96	750.5	I _B - I' _B	1.8	4.1	6.5	0.2
431	14.2	96	750.5	I _D	79.3	85.7	91.0	0.2
431	14.2	96	750.5	I' _D	63.5	68.2	74.0	0.3
429	20.2	79	750.5	I _B	42.2	45.4	49.5	0.6
429	20.2	79	750.5	I' _B	38.2	41.1	44.2	0.5
429	20.2	79	750.5	I _B - I' _B	1.6	4.3	8.3	0.6
429	20.2	79	750.5	I _D	46.7	53.7	59.8	0.6
429	20.2	79	750.5	I' _D	35.5	39.6	44.1	0.4
427	27.7	54	750.5	I _B	14.8	17.3	20.3	0.2
427	27.7	54	750.5	I' _B	8.0	10.5	13.1	0.3
427	27.7	54	750.5	I _B - I' _B	4.0	6.8	9.8	0.3
427	27.7	54	750.5	I _D	15.8	21.3	26.9	0.3
427	27.7	54	750.5	I' _D	4.5	8.7	13.0	0.3
434	9.7	206	805.5	I _B	166.0	173.0	178.8	3.5
434	9.7	206	805.5	I' _B	177.4	183.8	189.7	3.5
434	9.7	206	805.5	I _B - I' _B	-14.6	-10.7	-7.7	0.6
434	9.7	206	805.5	I _D	179.3	186.9	195.0	3.5
434	9.7	206	805.5	I' _D	161.9	168.7	174.9	3.5
432	14.2	161	805.5	I _B	112.6	117.9	122.8	0.2
432	14.2	161	805.5	I' _B	111.3	116.9	122.5	0.2
432	14.2	161	805.5	I _B - I' _B	-2.5	1.1	4.7	0.5
432	14.2	161	805.5	I _D	131.0	138.3	144.9	0.3
432	14.2	161	805.5	I' _D	110.1	116.1	122.3	0.2
430	20.2	123	805.5	I _B	67.1	71.6	76.3	0.5
430	20.2	123	805.5	I' _B	61.5	65.7	70.4	0.6
430	20.2	123	805.5	I _B - I' _B	1.3	6.0	12.3	0.6
430	20.2	123	805.5	I _D	75.6	85.1	94.0	0.6
430	20.2	123	805.5	I' _D	61.2	65.9	70.9	0.6
428	27.7	89	805.5	I _B	24.3	28.5	32.8	0.4
428	27.7	89	805.5	I' _B	14.0	18.5	22.5	0.2
428	27.7	89	805.5	I _B - I' _B	5.7	10.0	18.1	0.5
428	27.7	89	805.5	I _D	22.3	32.6	41.3	0.5
428	27.7	89	805.5	I' _D	**	**	**	**

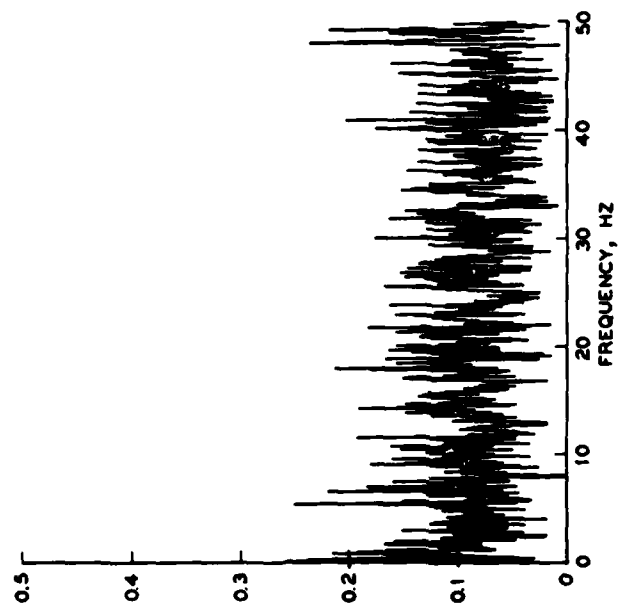
* Very little pressure at all frequencies.
** Data not recoverable.



TIME-HISTORY

MEAN STATIC PRESSURE = 5.4

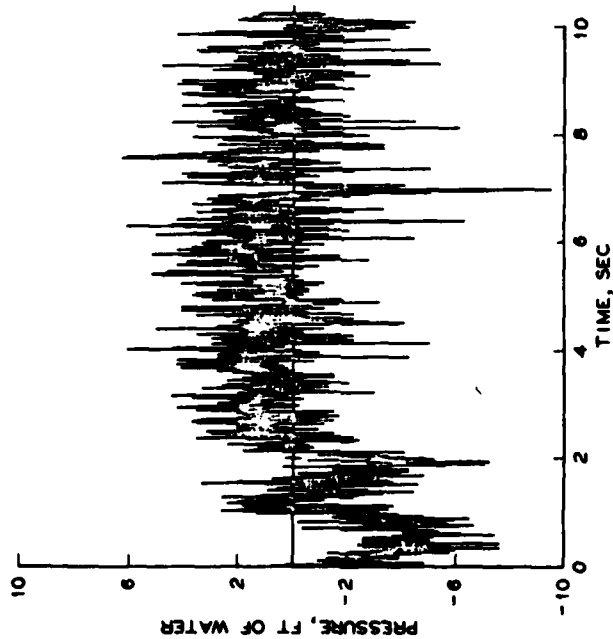
MASTER VANE. 6.00
 POOL EL. 808
 VALVE OPENING 25%



AMPLITUDE SPECTRUM

PREDOMINANT FREQUENCY = 0.2

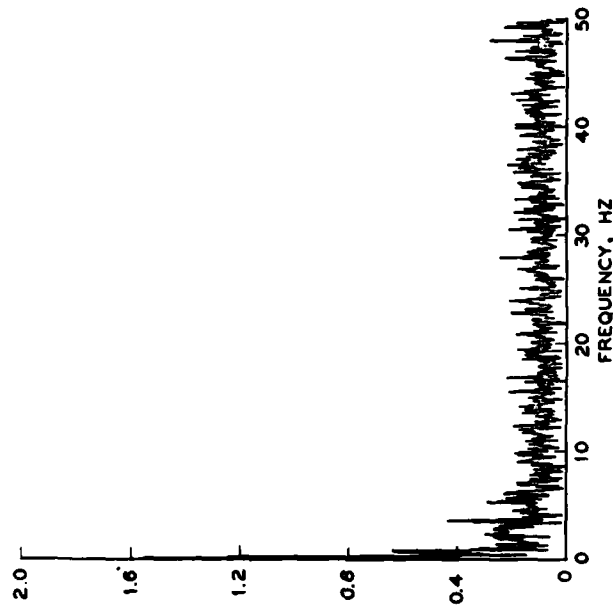
DIFFERENTIAL VANE PRESSURE
 FLOOD CONTROL AND IRRIGATION OUTLET
 TEST 721 TRANSDUCER I_b-I₆
 LOW-HEAD TEST



TIME-HISTORY

MEAN STATIC PRESSURE = 7.6

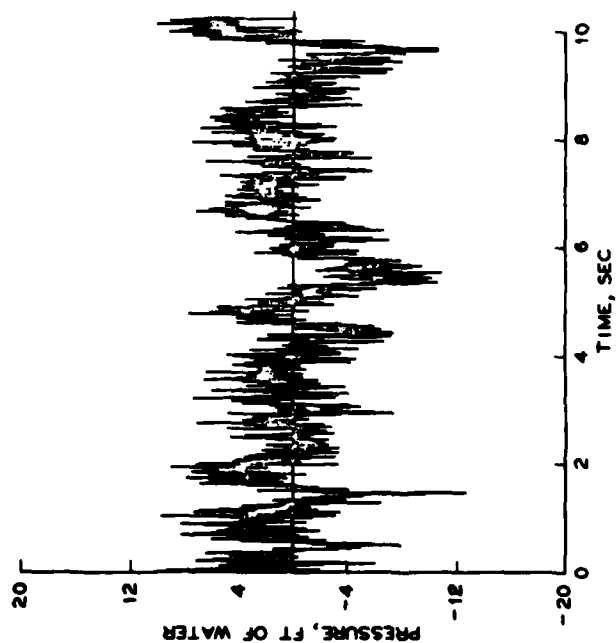
MASTER VANE . . . 600
 POOL EL 808
 VALVE OPENING . . . 40%



AMPLITUDE SPECTRUM

PREDOMINANT FREQUENCY = 0.2

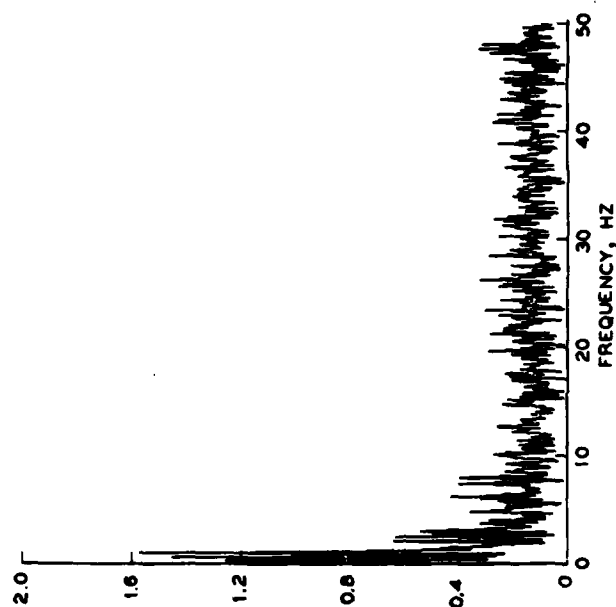
DIFFERENTIAL VANE PRESSURE
 FLOOD CONTROL AND IRRIGATION OUTLET
 TEST 720 TRANSDUCER I_D-I₀
 LOW-HEAD TEST



TIME-HISTORY

MEAN STATIC PRESSURE = 9.8

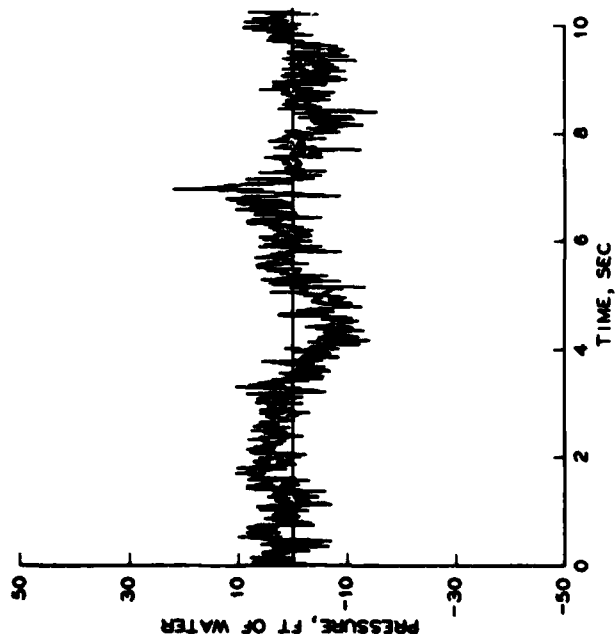
MASTER VANE. 6.00
 POOL EL. 808
 VALVE OPENING 60%



AMPLITUDE SPECTRUM

PREDOMINANT FREQUENCY = 1.1

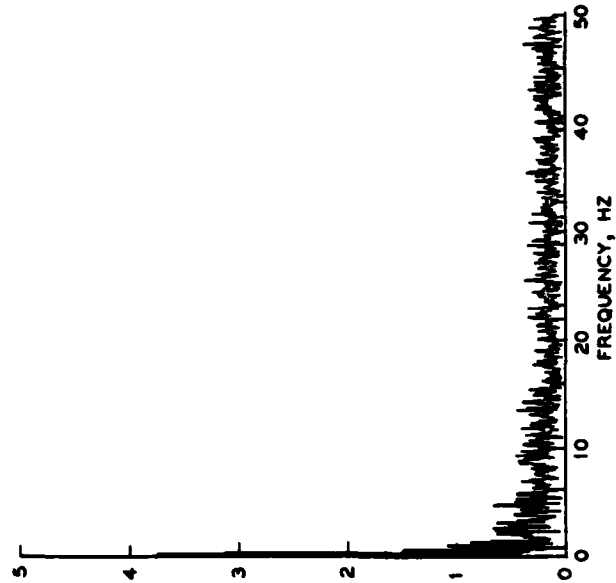
DIFFERENTIAL VANE PRESSURE
 FLOOD CONTROL AND IRRIGATION OUTLET
 TEST 719 TRANSDUCER I_D-I_b
 LOW-HEAD TEST



TIME-HISTORY

MEAN STATIC PRESSURE = 12.9

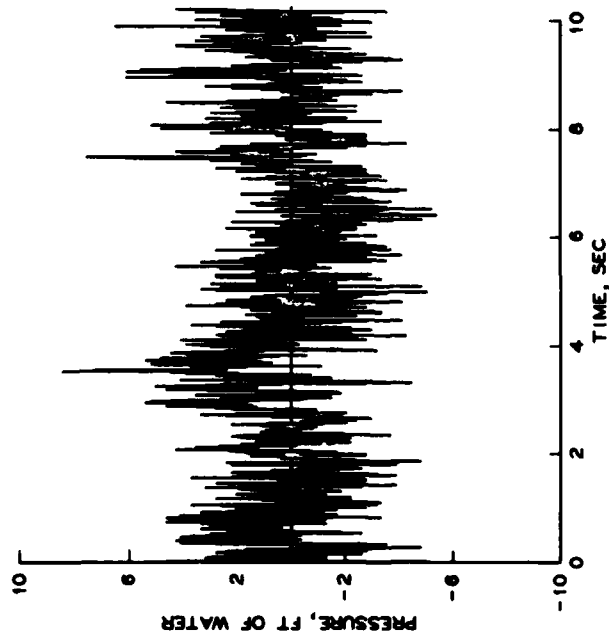
MASTER VANE . . . 6.00
 POOL EL 808
 VALVE OPENING . . . 85%



AMPLITUDE SPECTRUM

PREDOMINANT FREQUENCY = 0.3

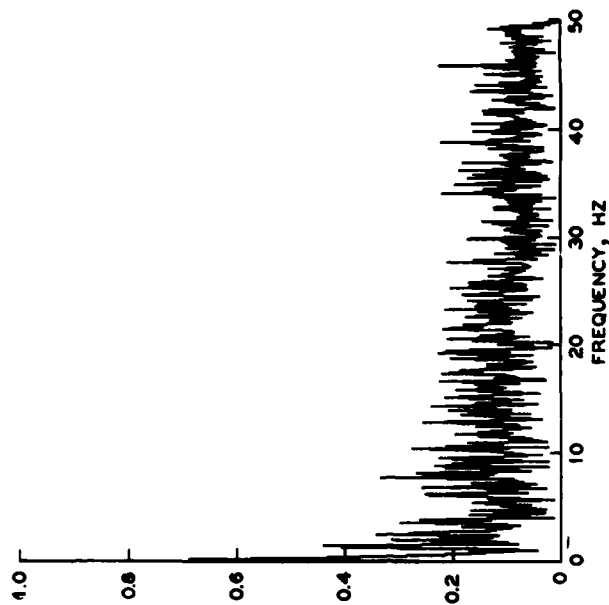
DIFFERENTIAL VANE PRESSURE
 FLOOD CONTROL AND IRRIGATION OUTLET
 TEST 718 TRANSDUCER I_D-I₀
 LOW-HEAD TEST



TIME-HISTORY

MEAN STATIC PRESSURE = 2.8

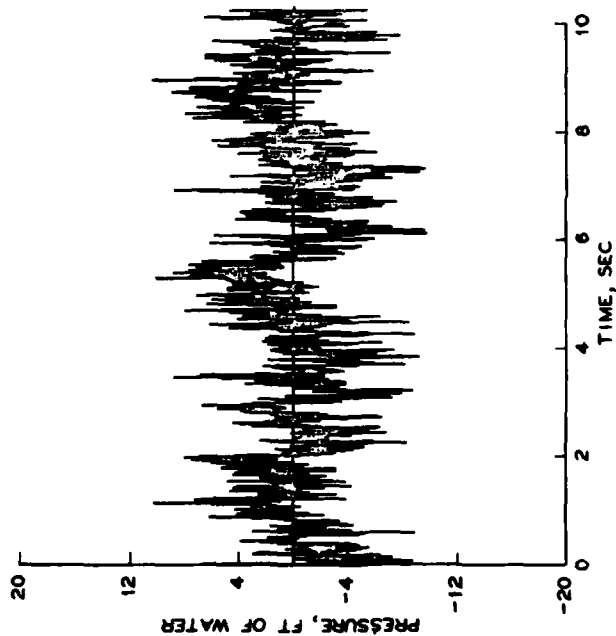
MASTER VANE..... 6.00
 POOL EL..... 950
 VALVE OPENING..... 25%



AMPLITUDE SPECTRUM

PREDOMINANT FREQUENCY = 0.3

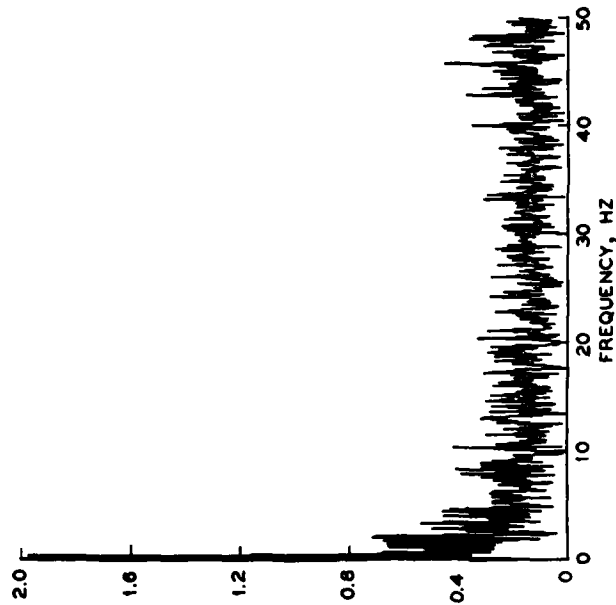
DIFFERENTIAL VANE PRESSURE
 FLOOD CONTROL AND IRRIGATION OUTLET
 TEST 713 TRANSDUCER I_b-I_b
 LOW-HEAD TEST



TIME-HISTORY

MEAN STATIC PRESSURE = 7.2

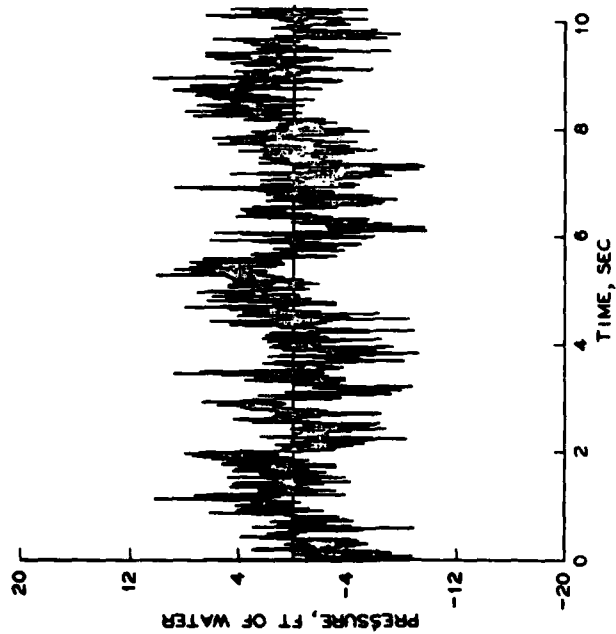
MASTER VANE. 6.00
 POOL EL. 950
 VALVE OPENING 40%



AMPLITUDE SPECTRUM

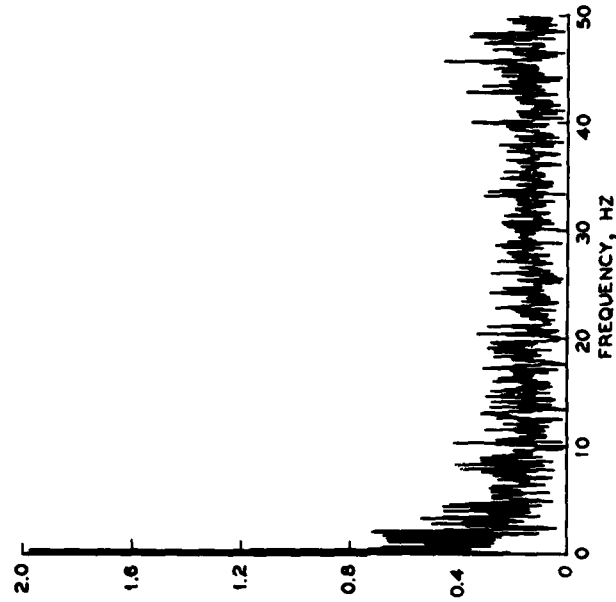
PREDOMINANT FREQUENCY = 0.4

DIFFERENTIAL VANE PRESSURE
 FLOOD CONTROL AND IRRIGATION OUTLET
 TEST 712 TRANSDUCER I₀-I₀
 LOW-HEAD TEST



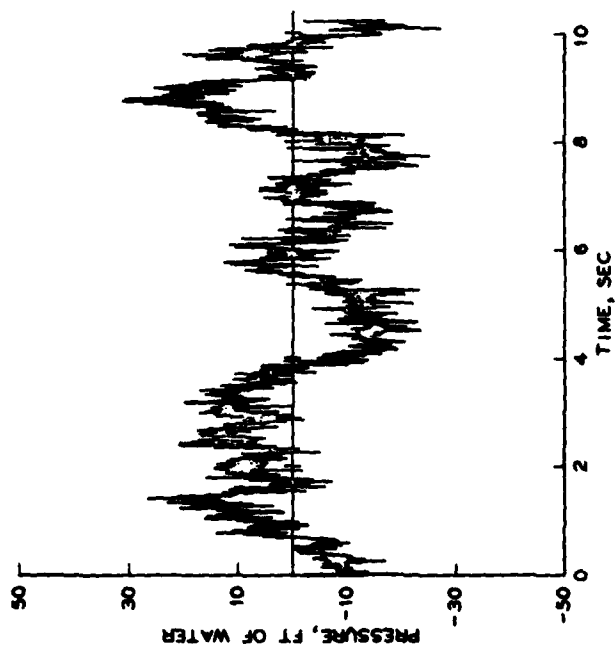
TIME-HISTORY
MEAN STATIC PRESSURE = 7.2

MASTER VANE 6.00
POOL EL 950
VALVE OPENING 40%



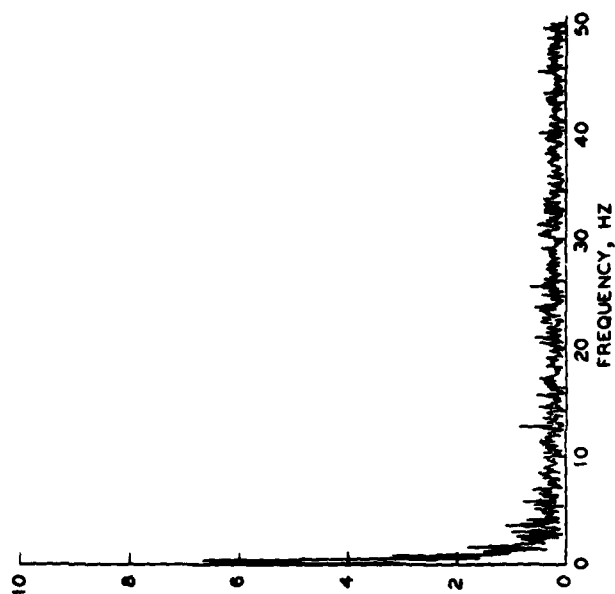
AMPLITUDE SPECTRUM
PREDOMINANT FREQUENCY = 0.4

DIFFERENTIAL VANE PRESSURE
FLOOD CONTROL AND IRRIGATION OUTLET
TEST 712 TRANSDUCER I_D-I_b
LOW-HEAD TEST



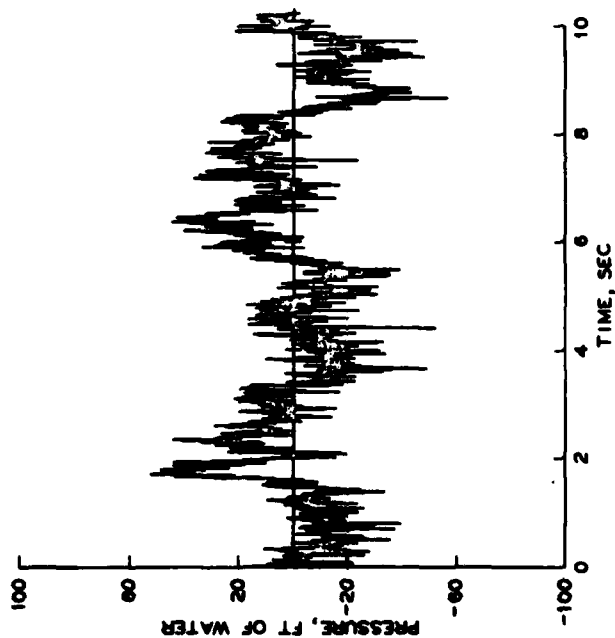
TIME-HISTORY
MEAN STATIC PRESSURE = 33.8

MASTER VANE ... 6.00
POOL EL ... 950
VALVE OPENING ... 60%



AMPLITUDE SPECTRUM
PREDOMINANT FREQUENCY = 0.5

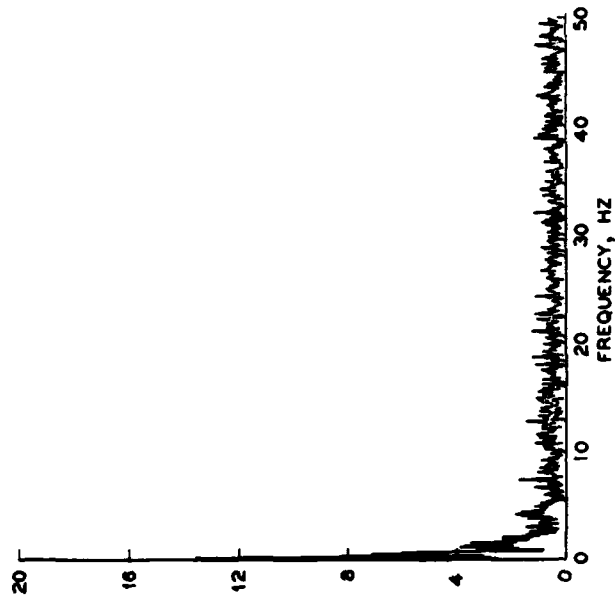
DIFFERENTIAL VANE PRESSURE
FLOOD CONTROL AND IRRIGATION OUTLET
TEST 723 TRANSDUCER $I_D - I_b$
LOW-HEAD TEST



TIME-HISTORY

MEAN STATIC PRESSURE = 45.1

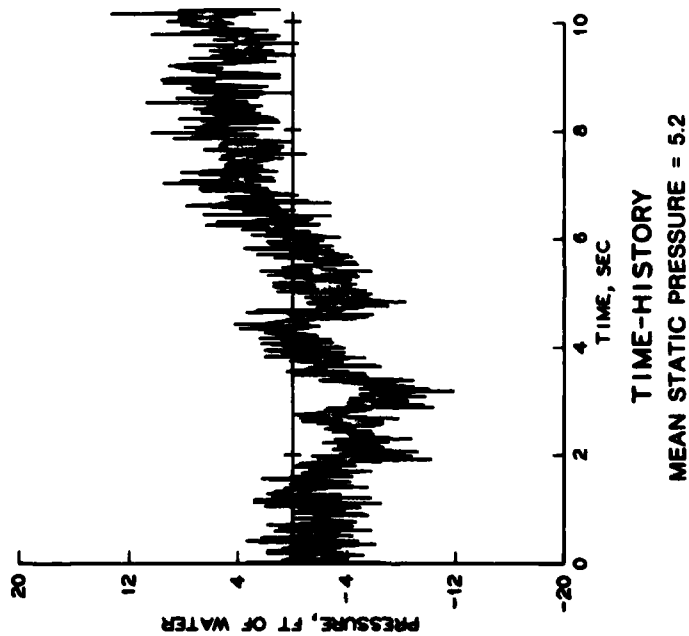
MASTER VANE 6.00
 POOL EL 950
 VALVE OPENING 85%



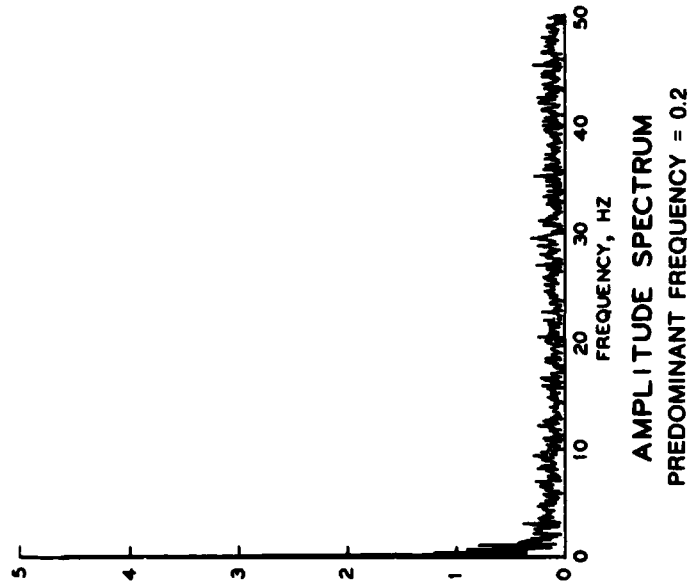
AMPLITUDE SPECTRUM

PREDOMINANT FREQUENCY = 0.3

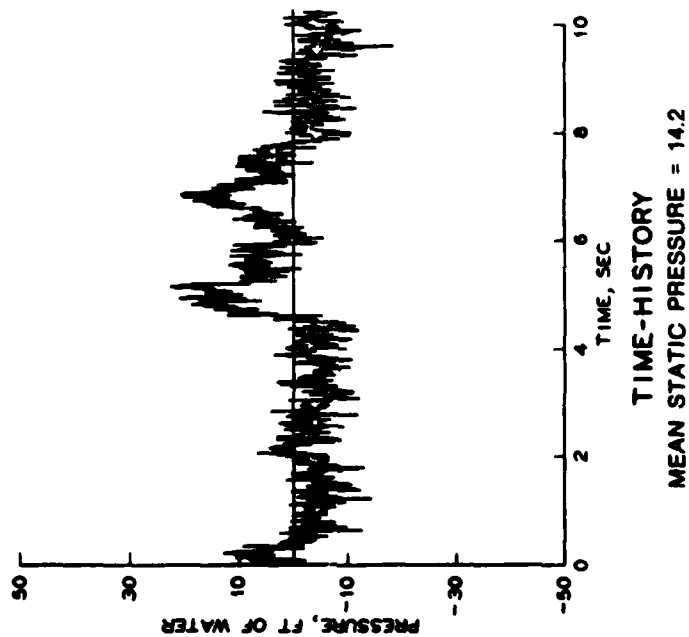
DIFFERENTIAL VANE PRESSURE
 FLOOD CONTROL AND IRRIGATION OUTLET
 TEST 722 TRANSDUCER I₀-I₆
 LOW-HEAD TEST



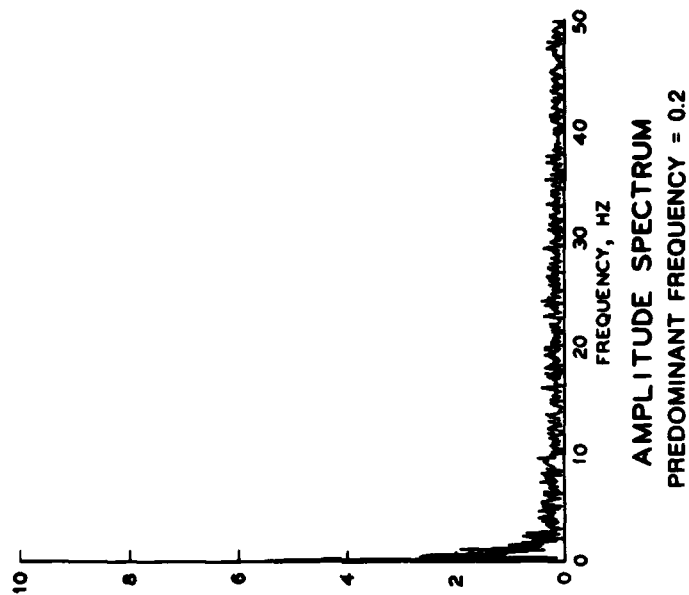
MASTER VANE 6.00
 POOL EL 1048
 VALVE OPENING 25%



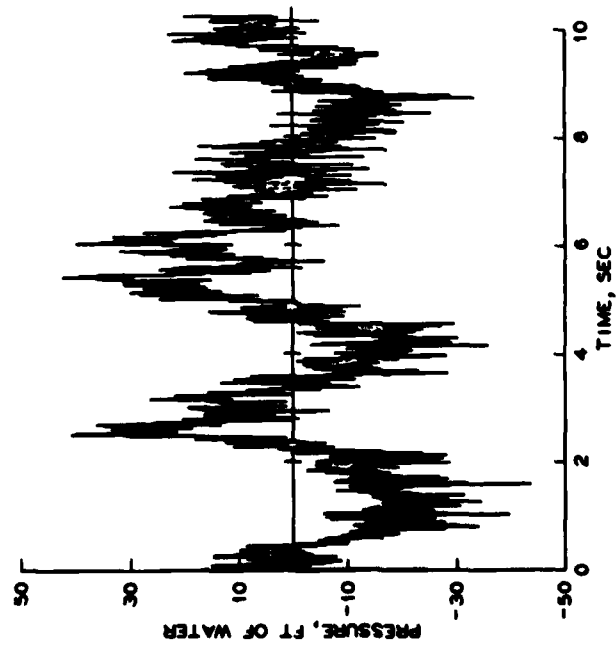
DIFFERENTIAL VANE PRESSURE
 FLOOD CONTROL AND IRRIGATION OUTLET
 TEST 717 TRANSDUCER I₀-I₆
 LOW-HEAD TEST



MASTER VANE 6.00
 POOL EL 1048
 VALVE OPENING 40%



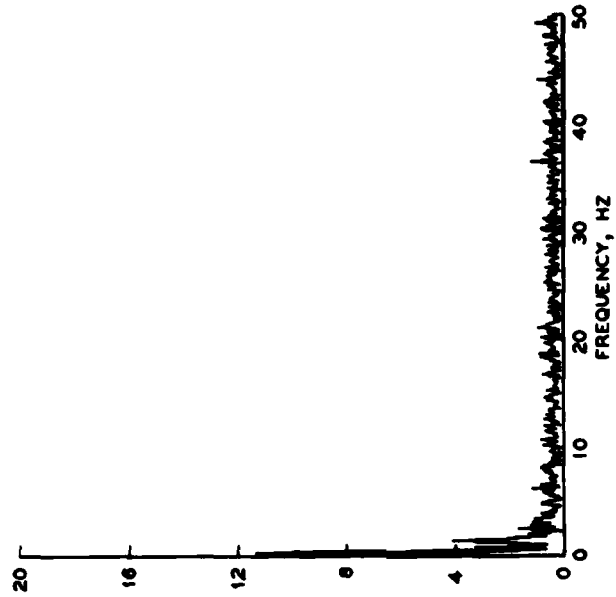
DIFFERENTIAL VANE PRESSURE
 FLOOD CONTROL AND IRRIGATION OUTLET
 TEST 716 TRANSDUCER I₀-I₆
 LOW-HEAD TEST



TIME-HISTORY

MEAN STATIC PRESSURE = 34.9

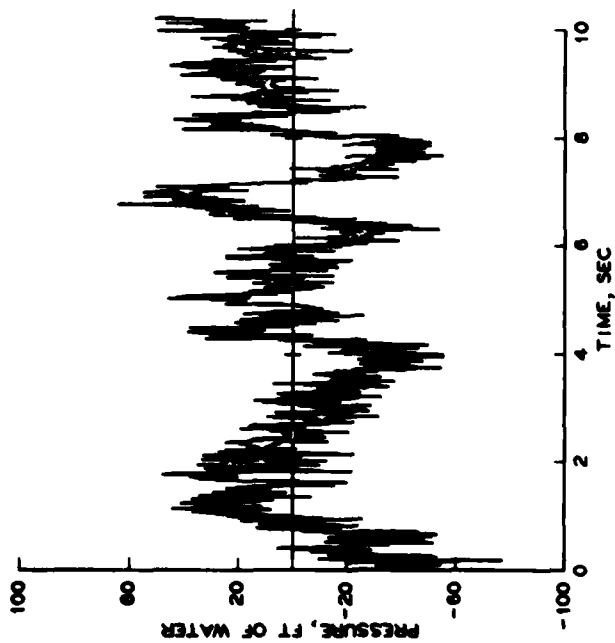
MASTER VANE 6.00
 POOL EL 1046
 VALVE OPENING 60%



AMPLITUDE SPECTRUM

PREDOMINANT FREQUENCY = 0.4

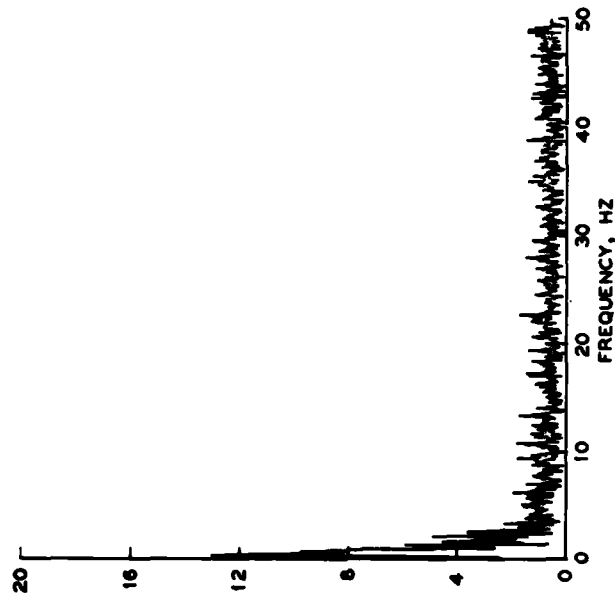
DIFFERENTIAL VANE PRESSURE
 FLOOD CONTROL AND IRRIGATION OUTLET
 TEST 715 TRANSDUCER I₀-I₆
 LOW-HEAD TEST



TIME-HISTORY

MEAN STATIC PRESSURE = 64.1

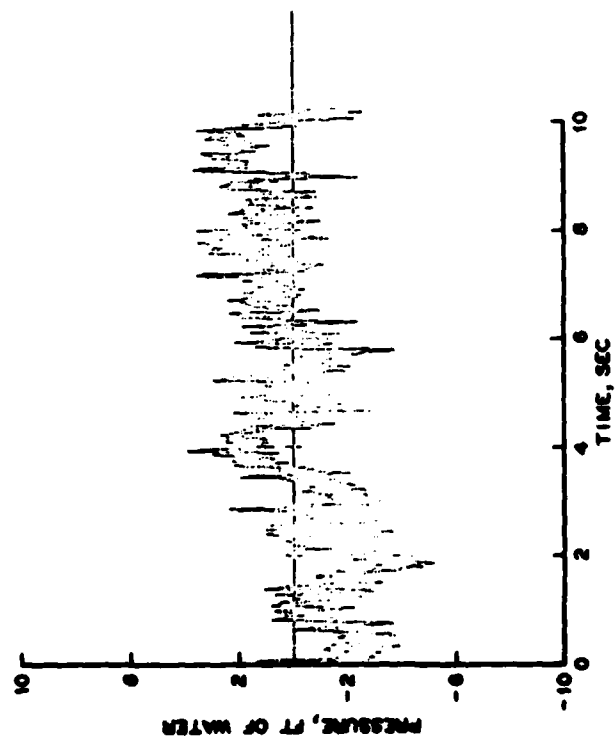
MASTER VANE . . . 6.00
 POOL EL 1048
 VALVE OPENING . . . 65%



AMPLITUDE SPECTRUM

PREDOMINANT FREQUENCY = 0.4

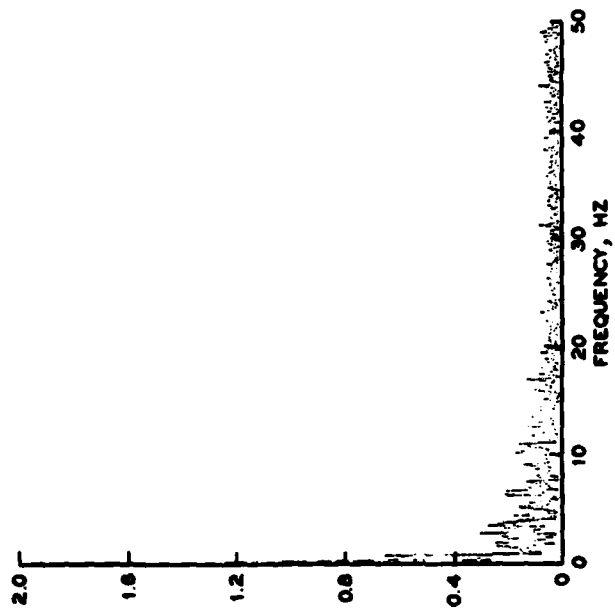
DIFFERENTIAL VANE PRESSURE
 FLOOD CONTROL AND IRRIGATION OUTLET
 TEST 714 TRANSDUCER I_D-I_b
 LOW-HEAD TEST



TIME-HISTORY

MEAN STATIC PRESSURE = 12.2

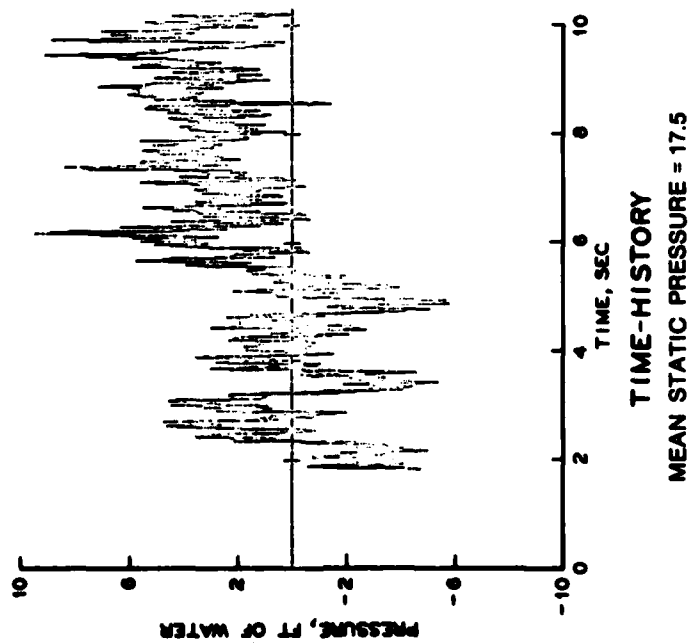
MASTER VANE 10.30
 POOL EL 750.5
 SLEEVE TRAVEL 9.7 IN.



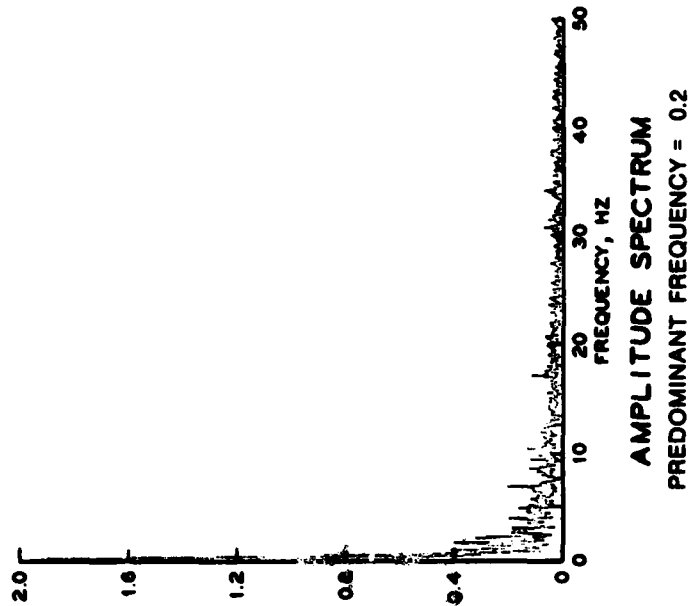
AMPLITUDE SPECTRUM

PREDOMINANT FREQUENCY = 0.2

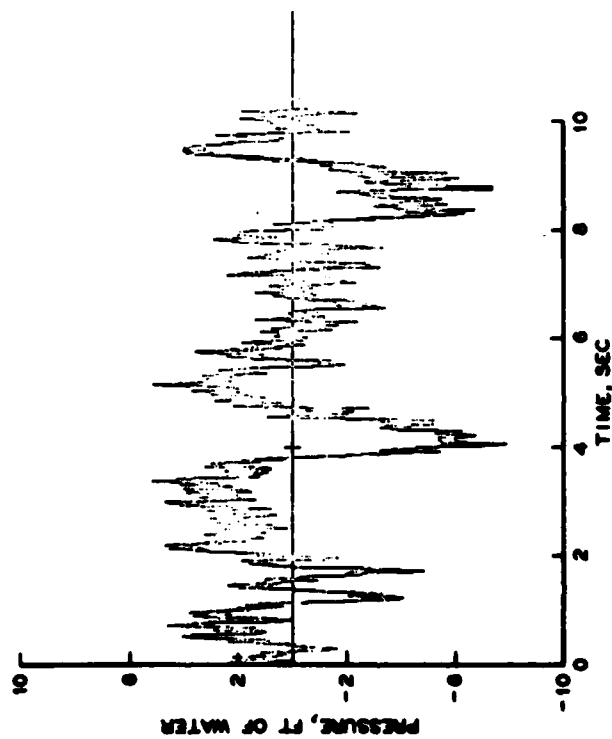
DIFFERENTIAL VANE PRESSURE
 LOW-LEVEL OUTLET
 TEST 433 TRANSDUCER I_b-I_b
 LOW-HEAD TEST



MASTER VANE 10.30
POOL EL 750.5
SLEEVE TRAVEL 14.2 IN.

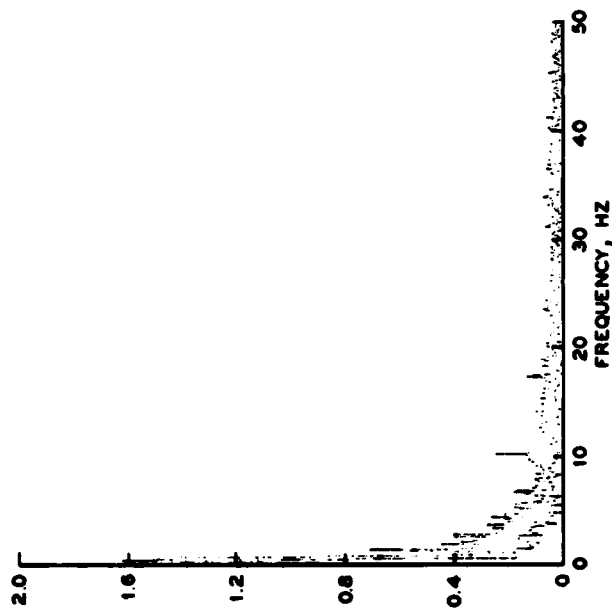


DIFFERENTIAL VANE PRESSURE
LOW-LEVEL OUTLET
TEST 431 TRANSDUCER 1₀-1₆
LOW-HEAD TEST



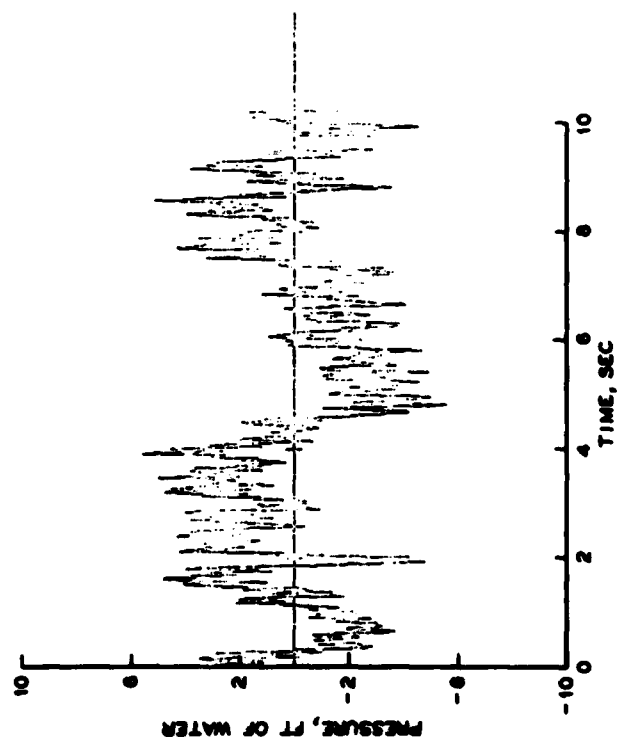
MEAN STATIC PRESSURE = 14.1

MASTER VANE 10.30
 POOL EL 750.5
 SLEEVE TRAVEL 20.2 IN.



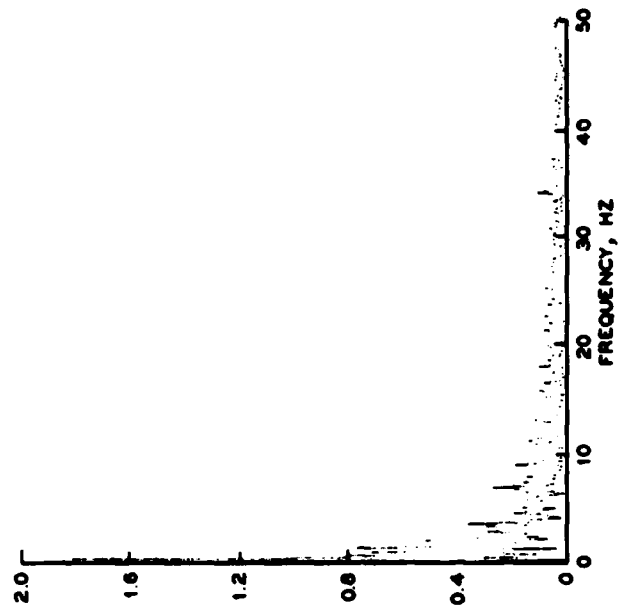
PREDOMINANT FREQUENCY = 0.5

DIFFERENTIAL VANE PRESSURE
 LOW-LEVEL OUTLET
 TEST 429 TRANSDUCER I₀-I₆
 LOW-HEAD TEST



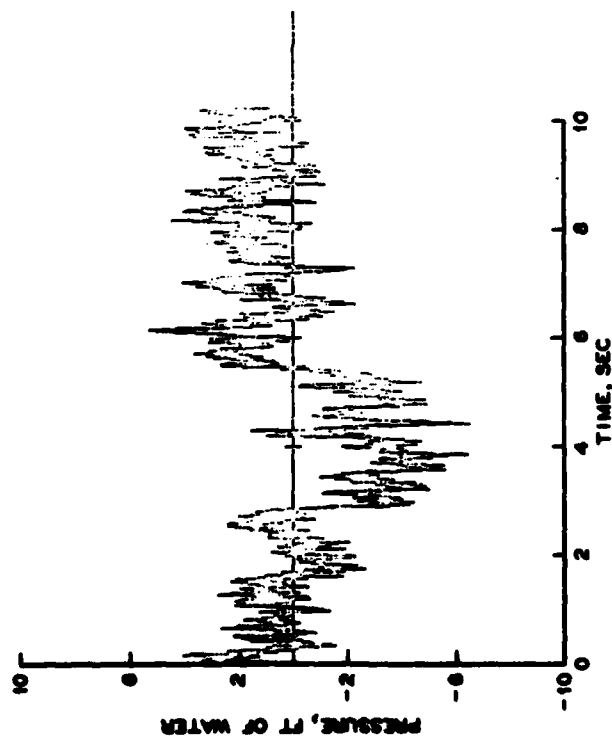
MEAN STATIC PRESSURE = 12.6

MASTER VANE 10.30
 POOL EL 750.5
 SLEEVE TRAVEL 27.7 IN.



PREDOMINANT FREQUENCY = 0.3

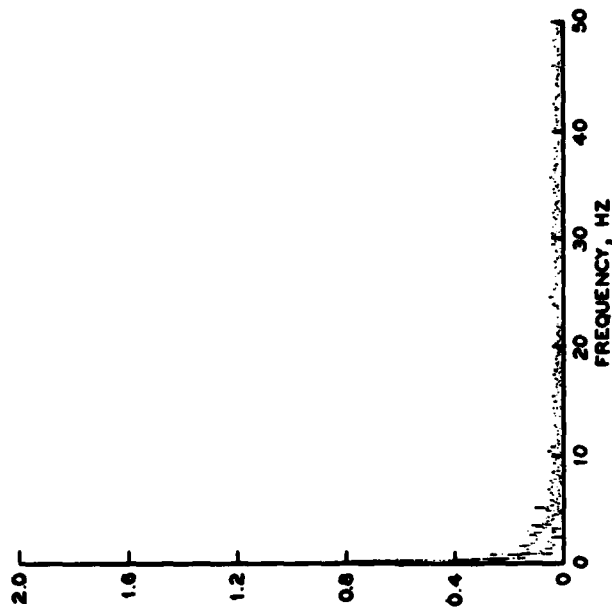
DIFFERENTIAL VANE PRESSURE
 LOW-LEVEL OUTLET
 TEST 427 TRANSDUCER I₀-I₆
 LOW-HEAD TEST



TIME-HISTORY

MEAN STATIC PRESSURE = 18.1

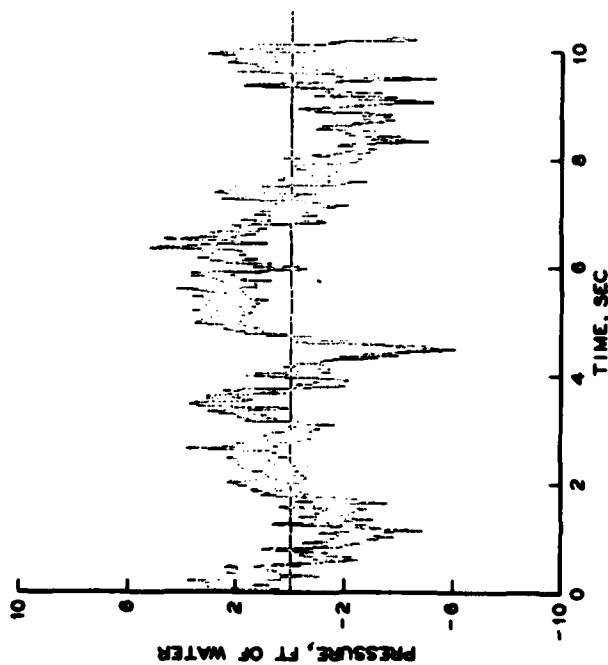
MASTER VANE 10.30
 POOL EL 805.5
 SLEEVE TRAVEL 8.7 IN.



AMPLITUDE SPECTRUM

PREDOMINANT FREQUENCY = 0.2

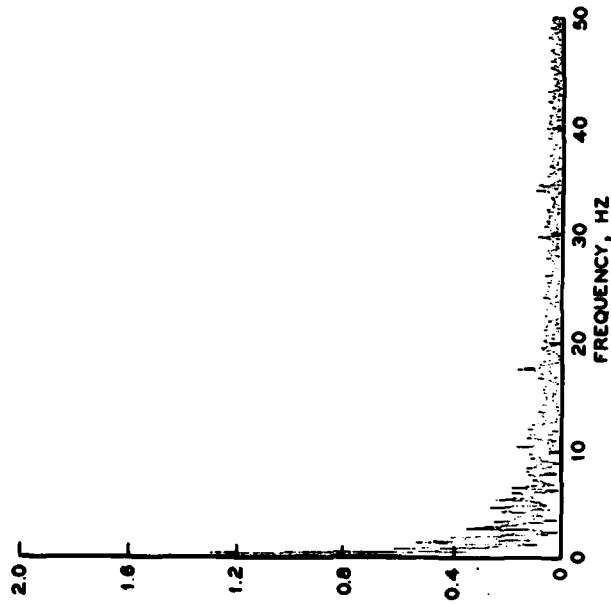
DIFFERENTIAL VANE PRESSURE
 LOW-LEVEL OUTLET
 TEST 434 TRANSDUCER I_D - I_B
 LOW-HEAD TEST



TIME-HISTORY

MEAN STATIC PRESSURE = 22.3

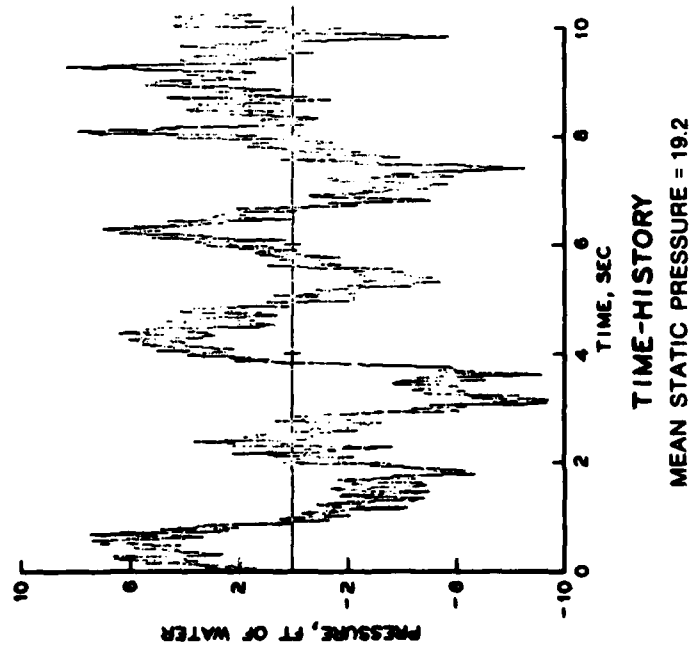
MASTER VANE 10.30
 POOL EL 805.5
 SLEEVE TRAVEL 14.2 IN.



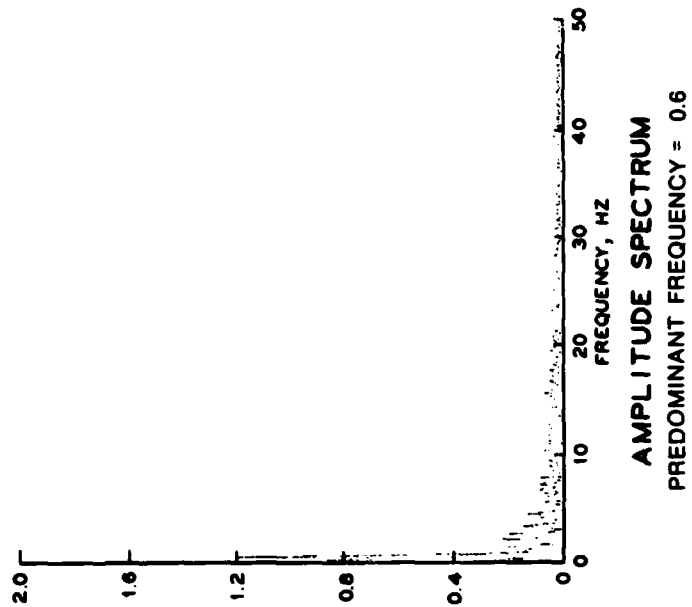
AMPLITUDE SPECTRUM

PREDOMINANT FREQUENCY = 0.4

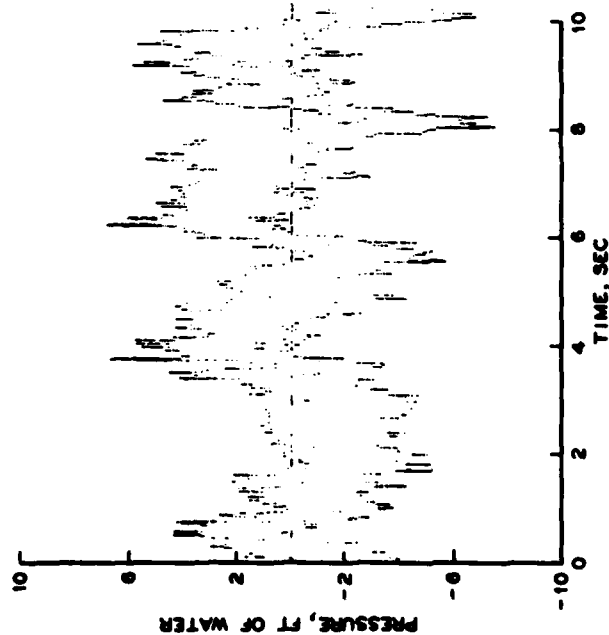
DIFFERENTIAL VANE PRESSURE
 LOW-LEVEL OUTLET
 TEST 432 TRANSDUCER I_D-I_b
 LOW-HEAD TEST



MASTER VANE 10.30
 POOL EL 805.5
 SLEEVE TRAVEL 20.2 IN



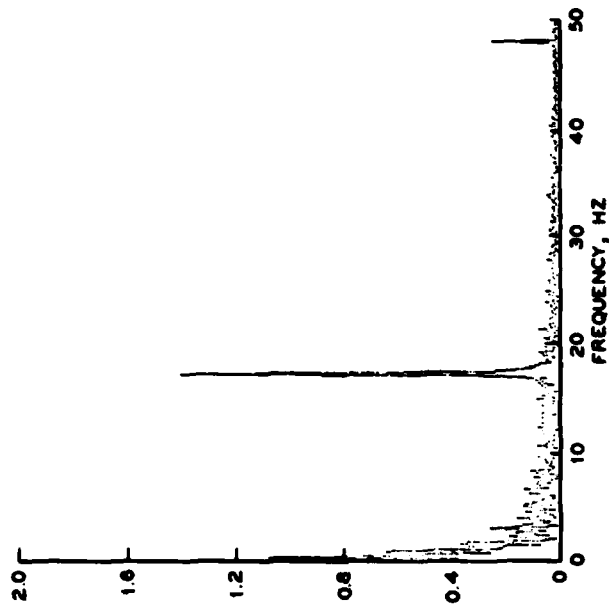
DIFFERENTIAL VANE PRESSURE
 LOW-LEVEL OUTLET
 TEST 430 TRANSDUCER I₀-I_b
 LOW-HEAD TEST



TIME-HISTORY

MEAN STATIC PRESSURE = 39.6

MASTER VANE 10.30
 POOL EL 805.5
 SLEEVE TRAVEL 27.7 IN.



AMPLITUDE SPECTRUM

PREDOMINANT FREQUENCY = 17.4

DIFFERENTIAL VANE PRESSURE
 LOW-LEVEL OUTLET
 TEST 428 TRANSDUCER I_D-I_b
 LOW-HEAD TEST

In accordance with letter from DAEN-RDC, DAEN-ASI dated 22 July 1977, Subject: Facsimile Catalog Cards for Laboratory Technical Publications, a facsimile catalog card in Library of Congress MARC format is reproduced below.

Maynard, Stephen T

Fixed-cone valves, New Melones Dam, California : Hydraulic model investigation : Final report / by Stephen T. Maynard, John L. Grace, Jr. (Hydraulics Laboratory, U.S. Army Engineer Waterways Experiment Station) ; prepared for U.S. Army Engineer District, Sacramento. -- Vicksburg, Miss. : U.S. Army Engineer Waterways Experiment Station ; Springfield, Va. : available from NTIS, 1981.

41, [15] p., [31] leaves of plates : ill. ; 27 cm. -- (Technical report / U.S. Army Engineer Waterways Experiment Station ; HL-81-4)

Cover title.

"April 1981."

Includes bibliographies.

1. Hydraulic models. 2. Hydraulic structures. 3. New Melones Dam (Calif.). I. Grace, John L. II. United States. Army. Corps of Engineers. Sacramento District.

Maynard, Stephen T.

Fixed-cone valves, New Melones Dam, California : ... 1981.
(Card 2)

III. United States. Army Engineer Waterways Experiment Station. Hydraulics Laboratory. IV. Title V. Series: Technical report (United States. Army Engineer Waterways Experiment Station) ; HL-81-4.

TA7.W34 no.HL-81-4